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PAPERS AND PROCEEDINGS OF

The Royal Society of Tasmania

Edited by M. R. Banks and S. J. Smith

and Published by the Society

Hobart, Tasmania

July 1985

Volume 119

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3 - OCT 1985
NATURAL HISTORY

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MUSEUM OF VICTORIA
3 - OCT 1985
NATURAL HISTORY

PAPERS AND PROCEEDINGS OF THE ROYAL SOCIETY OF TASMANIA
Volume 119

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ROYAL SOCIETY OF TASMANIA

ANNUAL REPORT FOR THE YEAR 1984

The Council has the honour to present to members the following report on the activities of the Society during the year.

COUNCIL AND OFFICE BEARERS

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Mr R.J. Dwyer

Honorary Editor
Dr M.R. Banks

Honorary Assistant Editor
Dr S.J. Smith

President

Sir James Plimsoll took the Chair, as President of the Society, at the Annual General Meeting in March.

Annual Meeting

At the Annual Meeting on 6 March, Mr L.E. Wall retired as Vice President and Miss R.H Barnett and Mr I.D. Geard as Members of the Council. The following were elected:

Vice-President	Mr I.D. Geard
Members of Council	Mr D. Hughes
	Mr C.A. Payne
Honorary Secretary	Mr D.R. Gregg
Honorary Treasurer	Mr T.A.H. Knight
Honorary Auditor	Mr R.J. Dwyer

Membership

The membership is 464, the same as 1982 and 1983, and is made up as follows:

	Northern Branch	Total
Honorary Life Members	2	5
Life Members	9	34
Ordinary Members receiving the Papers and Proceedings	70	284
Ordinary Members not receiving the Papers and Proceedings	67	123
Associate Members	14	18
	162	464

Vernon Victor Hickman, OBE, (1894–1984)

Professor Emeritus V.V. Hickman died in Hobart on 20 November 1984, aged 90.

Professor Hickman joined the Society in 1915 and gave dedicated service both as a member and office-holder. He was awarded the Royal Society of Tasmania medal in 1940 and the Clive Lord Memorial Medal in 1960. He was elected an Honorary Life Member in 1967.

The Council places on record its appreciation of his contributions both to the Society and to science and education during his long and active life.

Council Meetings

The Council met four times during the year with Mr D.G. Hannan and Mr C.B. Tassell representing the Northern Branch on the Council.

Library

The Library has continued to function smoothly during the year. The Librarian, Stefan Petrow, left in September on leave of absence to resume studies for a period, and he was replaced by Mrs Gaye Thavisin, working 65% of full-time. Mrs Jane Hutchison remains as part-time clerical assistant.

Visitors to the Library signing the register totalled 520 for 1984, a significant increase on last year's total of 380. Loans of material, chiefly from the Serials collection, numbered 290. The Library supplied 93 items, mainly photocopies, in response to interlibrary loan requests, both from within Australia and abroad, during the year.

Binding of periodicals remained a high priority, and during the year 889 volumes were bound.

In October 1984, 296 copies of Vol. 118 of the *Papers and Proceedings* were mailed to exchange partners, 54 volumes to partners in Australia, and 242 to partners elsewhere in the world. In the course of the year, our exchange agreement with the Elisha Mitchell Scientific Society was terminated.

Early in the year the Northern Branch of the Society sent its collection of surplus books to the Librarian. 46 titles not already held by the Library were added to its collection, and the remaining 59 titles were valued. These were subsequently offered for sale to members of the Northern Branch.

The following books were donated to the Library in 1984:

DALES, R.P., comp: *PRACTICAL INVERTEBRATE ZOOLOGY: A LABORATORY MANUAL FOR THE STUDY OF THE MAJOR GROUPS OF INVERTEBRATES, EXCLUDING PROTOCHORDATES*, University of Washington Press, 1970.

MUSE, C. & S.: *THE BIRDS AND BIRDLORE OF SAMOA*, Pioneer Press, 1982.

SCHOPF, T.J.M.: *PALEOCEANOGRAPHY*, Harvard University Press, 1980.

In addition two monographs were received from exchange partners:

CSIRO Division of Fisheries Research: SECOND DIVISIONAL RESEARCH SEMINAR, 19–23 March 1984.

RAOU Conservation Statement No. 1: THE GROUND PARROT "*PEZOPORUS WALLICUS* KERR", prepared by C.W. Meredith, 1984.

During the year the Rare Book Collection was reshelved more appropriately, the pamphlet collection thoroughly examined and stored correctly, and the Ernest Clark and history collections filed in one sequence for easier access.

Publications

Volume 118 of the Papers and Proceedings was published in August 1984. It contained 18 papers by 30 authors and totalled 248 pages.

A new method of production, involving the use of a word-processor, is to be employed for Volume 119.

The Society is once more indebted to Dr Banks and Dr Smith for their dedicated editorial work.

Lectures

The following lectures were given at General Meetings during the year:

March	'The East Australian Current'	Dr George Cresswell, CSIRO Division of Oceanography
April	'Some aspects of self defence in plants'	Professor J.V. Lovett, University of Tasmania
May	'A gaggle of greenies: 200 years of taxonomic botany in Tasmania'	Dr A.E. Orchard, Tasmanian Herbarium

June	'The 'Pandora' re-discovered'	Ms Shirley Lester, Queen Victoria Museum and Art Gallery
July	'The RAOU Bird Atlas 1977–1981: its objectives, organisation and achievements'	Dr O.M.G. Newman, Royal Australasian Ornithologists Union
August	'AIDS and other things that happen to some people'	Dr David Evans, Commonwealth Pathology Laboratory
September	'The Black War: a new look at an old story' Eldershaw Memorial Lecture. Joint meeting with Tasmanian Historical Research Association	Professor Henry Reynolds, James Cook University of Townsville
October	'Aquaculture: food, finance or fantasy?'	Dr T.G. Dix, Tasmanian Fisheries Development Authority
November	'EZ's role as a corporate citizen of Tasmania'	Mr W.T. Wise, Electrolytic Zinc Co. of Australasia Ltd
December	'Prehistoric archaeology in another Southern land'	Professor Hilary Deacon, University of Stellenbosch

Two excursions were held. On 9 June, a visit was made to the Tasmanian Herbarium. On 10 November, members visited the Risdon plant of the Electrolytic Zinc Company of Australasia Ltd.

Northern Branch

Chairman	Mr D.G. Hannan
Vice-Chairman	Mrs G.M. Morris
Past Chairman	Mr B.A. Pike
Council Members	Mr R.E. Ward
	Mr J.H. Chambers
	Dr D. Hamilton
	Mrs R.M. Cameron
Honorary Secretary	Mr C.B. Tassell
Honorary Treasurer	Mr K.E.J. Robinson
Branch representatives on the Council	Mr D.G. Hannan
	Mr C.B. Tassell

The Branch Council met six times during the year.

The following lectures were given at General Meetings:

March	His life as a musician	Mr Jan Sedivka, University of Tasmania
April	Pensions in retirement Investment in retirement	Mr Jamieson Mr Macdonald Launceston Bank for Savings
May	Aquaculture	Dr A. Osborne, Dr N. Forteith, Tasmanian College of Advanced Education
June	Forum — Allergies	Dr R. Mecoy, Dr D. Hamilton, Mr A. McLeod

July	'Pandora' expedition	Ms Shirley Lester, Queen Victoria Museum and Art Gallery
August	Macquarie Island	Ms Perviz Marker
September	Halley's Comet	Mr M. George, Queen Victoria Museum and Art Gallery
October	What Happens Inside Classrooms	Dr D. Fisher, Tasmanian College of Advanced Education
December	Members night:	
	Geology and Land Use of Lees Paddocks North West Tasmania	Mr D. Hannan
	Excursion to Port Arthur	Mr D. Walter
	Rev. George Eastman, Chaplain, Port Arthur	Mrs R. Ward

Symposium

A major symposium, organised jointly with ANZAAS, was presented in Launceston on Saturday 22 September. The topic, Bass Strait, covered the potential it offers Tasmania and the problems it has presented to the development of this state.

Ten guest speakers, with the Chairman Mr Jack Edwards discussed a number of subjects during the day-long symposium. Participating speakers were:

Dr S. Murray-Smith (University of Melbourne): Bass Strait Today — a Survey

Mr J.K. Davidson (Petrecon Australia Pty Ltd): The Geological Evolution and the Petroleum Industry of the Bass Basin

Dr C.B. Fandry (CSIRO Division of Oceanography): The Physical Oceanography of Bass Strait

Mr G.R. Stackhouse (President of the Australian Fishing Industry Council): Commercial Fisheries of Bass Strait

Mr B.J. Lynch (Premiers Department): Dimensions in Bass Strait Shipping — a Perspective

Mr R.T.J. Holyman and Mr O.J. Warren (Wm Holyman and Sons Pty Ltd): Bass Strait Transport: Development and Prospects

Mr K.V. Korofeeff (Proprietor of the King Island News): King Island's Resources are yet to be Tested

Mr J.D. Duigan ('Kronstadt', Flinders Island): Agriculture and Other Occupations and the Special Problems Confronting Island Communities with an overview and summary given by Professor G.N. Blainey of the University of Melbourne.

Associated with the symposium were exhibitions on maritime archaeology presented at the Launceston Bank for Savings and the Northern Regional Library.

Excursion

The November meeting took the form of an excursion from 3 to 5 November to the Port Arthur historic site.

Nominees to Other Bodies

The Council re-elected Dr M.R. Banks and Mr A.R. Neilson to the Board of Trustees of the Tasmanian Museum and Art Gallery. They report on the year's activities:

The 1984 State Budget provided $1 060 000 to the Tasmanian Museum and Art Gallery, an increase of only 6% on the previous year. The Trustees were gravely disappointed that the grant fell so far below their demonstrable needs. The amount able to be allocated for collection purchases was a very inadequate $50 000.

Funds have, however, enabled the permanent employment of three additional members of staff who were previously employed with Commonwealth funds under the Wage Pause Programme and the Australian Biological Resources Study.

The Wage Pause Programme and, later, the Community Employment Programme provided welcome sources of funds to employ otherwise unemployed people to assist with various projects. Under the Wage Pause Programme, eight people were employed for periods of up to 52 weeks. Grants under the Community Employment Programme enabled ten people to be employed for periods ranging from 14 to 52 weeks.

The Trustees continue to be disturbed at the lack of progress with building development for the Museum and Art Gallery in Hobart. They look forward, however, to resumption of work on the renovation of the buildings in 1985.

At Zeehan, the renovation of the first floor of the Post Office building has been completed and this will provide much-needed extra space for displays.

The Art Foundation of Tasmania, launched by His Excellency the Governor in July 1984, has encouraged support from the private sector for acquisitions for the collections of the Museum and Art Gallery. The Tasmanian Government has agreed to a dollar-for-dollar subsidy on donations up to a maximum subsidy of $225 000 over three years. The donations pledged by the 8 corporate and 16 individual members, together with the promised Government subsidy, totalled $190, 850 at the end of 1984.

During the 1984 year, 156 651 people visited the Tasmanian Museum and Art Gallery, compared with 144 877 in 1983. The America's Cup attracted record crowds when it was on show from 26 December 1983 to 8 January 1984.

Mr H.D. Barker, Preparator at the Museum and Art Gallery since 1971, died on 18 March 1984. During the last months of his life he completed a series of life-size models of the large mammals which lived in Tasmania towards the end of the Pleistocene, some 50 000 years ago. These were placed on display in December 1984.

A selection of 55 works by Simpkinson De Wesselow (1819–1906) from the Royal Society of Tasmania collection was placed on exhibition in December 1984 to mark the launching of the book on the artist by Mr Max Angus published by Blubber Head Press.

The Tasmanian Government, in August 1984, announced that all Tasmanian Aboriginal human remains held in the Tasmanian Museum and Art Gallery and the Queen Victoria Museum and Art Gallery were to be handed over to representatives of the Tasmanian Aboriginal community. Legislation to implement this decision, the *Museums (Aboriginal Remains) Act* 1984, was passed by Parliament in November 1984.

The Tasmanian State Service Act and other related Acts were passed by Parliament in May 1984. Amendments to the *Tasmanian Museum Act* 1950 drastically curtail the powers of the Trustees to employ staff. The new amendments also permit the Governor to dismiss the Chairman of Trustees if the Chairman refuses to comply with employment or administrative instructions issued under the *Tasmanian State Service Act*.

Dr Banks was re-elected Chairman of Trustees for a period of three months at the beginning of 1984. Mr Neilson was elected Chairman in May 1984. Dr Banks declined to be nominated for re-electin to the Trustees and at the end of 1984 finished a period of 11 years dedicated service on the Board.

Dr J.E.S. Townrow was re-elected by the Council to serve a further term on the Board of Trustees of the Royal Tasmanian Botanical Gardens. She reports on the year's activities:

The Trustees wish to congratulate the Superintendent, Mr A.P. May, on being awarded the Australian Nurserymen's Award of Merit 1984 for outstanding service to the industry. His dedicated work, coupled with the breaking of the seven year drought in spring this year, was reflected in the notably improved overall condition of the Gardens and the particularly good spring displays. Hopefully, the increased rains will result in a significantly lowered water rate compared with the $9 160 paid last financial year.

The total number of visitors to the Gardens was 228 506, a drop of 1% from the previous year. However, despite this drop, the number of visitors to the Museum and Education Centre rose by 30% to 24 674, the highest since its inception. This pleasing increase reflects the continued improvements in displays, the excellent work of Mr Alan Gray, Information and Education officer, and the altered opening hours of 12 noon to 4 p.m. The new Museum exhibits included a fern display in the Native Plant Room and seven framed charts of mounted native wildflowers of the Freycinet Peninsula, presented by Mrs Maureen Johnstone, replacing the previous set of SW Tasmania wildflowers in the Board Room. The Gardens' highly successful exhibit a the Royal Hobart Show 'Life Depends on Plants', designed by Mr Gray, will form the basis of a rotating display during 1985. A grant of $6 000 was received from the National Estate for the renewal of the Museum's old chimneys.

In compliance with the Trustees' recopgnition of the Gardens' special obligation to preserve and present Tasmanian native flora, especially endemic species, Mr Gray took part in an expedition in co-operation with NPWS to Cox's Bight to collect *Lomatia tasmanica* for conservation. He has also established a collection of *Rubus gunnianus*, a species potentially endangered by the rust fungus *Phragmidium violaceum* recently introduced to Australia.

Completed Gardens projects include the new Cactus and Succulent House, with one of the largest collections in Australia totalling more than

2 500, and the planted Camellia and Rhododendron Garden. The latter, designed and directed by Landscape Architect Dr J. Vitesnik employed a number of people funded under the Community Employment Programme Scheme.

Following contact from the Mayor of Hobart to the Mayor of Yaizu and reciprocal visits of staff and representatives to Tasmania and Japan, plans for a Japanese Garden in Hobart and an Australian Garden in Yaizu have been exchanged. The Japanese Garden will be sited in the Eastern Section beyond the French Memorial and rockeries, and below the new Erica and Proteaceae garden.

A Toyota Hortotherapy van, donated to the Gardens by the Rotary Club of Hobart and staffed by voluntary Friends of the Gardens and Probus Club drivers, has been extensively used by growing numbes of disabled and elderly people on conducted tours of the Gardens. The glasshouse and work area of the Easy Access Garden are now complete and it is expected that a Hortotherapist will be appointed in the New Year.

The Trustees have given close attention to confirming the Gardens' ownership of the foreshore area between the railway line and the River Derwent, not including that section formerly owned by the Gardens which was taken over by the Government for construction of the floating bridge and subsequently utilised for industrial purposes.

Acknowledgements

The Council is grateful for help generously given by many individuals and organisations. In particular, the lecturers, the Government of Tasmania, The University of Tasmania, the Tasmanian Museum and Art Gallery and the Queen Victoria Museum and Art Gallery are specially thanked for their help and cooperation.

ROYAL SOCIETY OF TASMANIA
Statement of Receipts and Payments
for the year ended 31 December 1984
General Account

Balance		5 011.82	Stationery	391.52
Subscriptions			Insurance	205.25
243 @ $12	2 920.00		Attendant's fees	818.62
109 @ $8	872.00		Secretarial fees	1 030.49
16 @ $5	80.00		Post box rental	100.00
Other years	186.00	4 058.00	Postage and freight	2 205.97
Interest		4 016.62	Photocopying	136.36
Rent		344.15	Subscriptions	577.45
Donations		18.52	Repairs & maintenance	5.80
Sales of publications and			Federal debit tax	23.30
Papers and Proceedings		1 829.86	Telephone	6.45
University subvention		6 355.00	Honour board	25.00
				5 526.21
			Typing of Papers and Proceedings	4 601.00
				10 127.21
			Balance carried forward	11 506.76
		$21 633.97		$21 633.97

Papers and Proceedings Account

Balance brought forward	1 038.77	Balance carried forward	1 583.25
Interest	544.48		
	$1 583.25		$1 583.25

Accumulation Account

Balance 1 January 1984		56 363.67
Add Increased cash at bank	7 332.09	
Net decrease in advance subscriptions	81.00	
Net increase in valuation of publications for sale	1 258.85	8 671.94
		65 035.61
Deduct Net transfers to Trust Funds		1 772.13
Balance 31 December 1984		$63 263.48

ROYAL SOCIETY OF TASMANIA
Balance Sheet as at 31 December 1984

1983		1984		1983		1984
56 363.67	Accumulated Funds		63 263.48	33.00	Cash on hand	33.00
210.00	Subscriptions in advance		129.00		Cash at bank:	
	Trust Funds:			5 011.82	— General Account	11 506 76
1 724.59	— Clive Lord Memorial Fund	1 901.95		1 038.77	— Papers & Proceedings Account	1 583.25
2 894.51	— A.N. Lewis Memorial Fund	3 191.57		278.78	— Clive Lord Memorial Fund	403.47
1 304.53	— Morton Allport Memorial	1 447.39		404.39	— A.N. Lewis Memorial Fund	572.27
524.56	— A.A. Clark Bequest	573.42		860.00	Mortgage Loan	860.00
3 551.62	— Joseph Milligan Bequest	3 904.18			Commonwealth Treasury Bonds	
1 914.07	— R.M. Johnston Memorial Fund	2 081.29		29 900.00	& Inscribed Stock (at cost)	29 900.00
838.68	— Henry Oliver Bequest	925.78		7 000.00	Interest Bearing Deposits	7 000.00
1 923.94	— W.H. Hudspeth Memorial	2 121.41		15 000.00	Library (at valuation for insurance)	15 000.00
3 121.79	— Life Membership Fund	3 423.43	19 570.42	14 845.20	Publications (at selling prices)	16 104.05
$74 371.96			$82 962.90	$74 371.96		$82 962.90

Papers and Proceedings of the Royal Society of Tasmania 119, 1985.

3 - OCT 1985
NATURAL HISTORY

ARTHUR COTTON AND IRRIGATION IN TASMANIA 1839-43

by G. Blackburn

BLACKBURN, G., 1985 (31:vii): Arthur Cotton and irrigation in Tasmania 1839–43. *Pap.Proc. R.Soc.Tasm.* 119:1–5. ISSN 0080-4703, 78 Allinga Ave, Glenunga, South Australia, 5064.

Cotton, an officer of the East India Company with experience of irrigation, visited Tasmania for periods totalling three years. His influence was important in gaining acceptance of irrigation as an aid to cereal production and the livestock industry. Details are given of his Tasmanian work, which had particular significance there for its emphasis on water conservation.

Key Words: Irrigation, Tasmania, Arthur Cotton.

INTRODUCTION

Arthur Thomas Cotton (1803–99) was the first engineer skilled in irrigation to visit Tasmania. He took a positive but unofficial interest in irrigation there during 1838–40 and 1841–43. A scheme for one locality was then successful, irrigation was extended by landowners in other districts, and work commenced on a major scheme for water conservation and irrigation. Although that project was soon abandoned during an economic recession, irrigation continued on several estates, as shown by Martelli (1861).

The early establishment of irrigation in Tasmania was ignored in Deakin's (1892) review of Australian irrigation, which mentions many individual irrigators, and in numerous accounts of large Australian schemes for irrigation. Roberts (1924, p.345), however, mentioned the abortive Tasmanian project. He gave credit for it to Major Cotton, apparently unaware that two brothers — Captain (Arthur) and Major (Hugh) Cotton — were associated with Tasmanian irrigation, for he did not indicate that Captain Cotton wrote the earliest of the papers noted by him as pertaining to Major Cotton. Captain Cotton's paper was published by the Tasmanian Society, and some early contributions on Tasmanian affairs certainly referred to him. Recent articles on the historic Long Marsh dam site (Scarborough and Brand 1975, Gowlland 1980) have given him some prominence. This paper attempts to clarify Arthur Cotton's role in the early years of Tasmanian irrigation.

The grandson of a baronet, Cotton grew up near Reading, England. In 1818 he entered Addiscombe College, the military academy of the East India Company, and was trained as a military engineer. After arrival in Madras in 1821, he worked on engineering projects, fought in the Burma Wars of 1824–25, and was later occupied mainly with irrigation works in southern India. He achieved great distinction as an engineer (Sandes 1935, p.28).

VISITS TO TASMANIA

Arthur Cotton's three visits to Australia were mentioned by his daughter (Hope 1900). The East India Company at times granted long leave on sick certificate to Cotton. On the first such period he was able to return to England, but service rules ensured that next time his choice of travel abroad was limited to South Africa or Australia (Hope 1900, pp.20–22). Britons in India were then being attracted to Tasmania (Henderson 1832) and Sydney Cotton (Pike 1966–67, v. 1,p.250) could have given fraternal encouragement about that colony. All of his visits to Australia occurred during periods of sick leave, for which the dates have been established. His arrivals in Tasmania are recorded in archives.

Captain Cotton reached Hobart in the *Guillardon* on 12 December 1838 with leave until April 1840, later extended to October 1840. His host in the colony was given as Captain Beecher (Hope 1900, p.23), a name not found in records of arrivals in Tasmania. However, for 25 August 1838 those records list "Becher", an homophonous variant of Beecher. Lieutenant Henry Murray Becher in March 1838 took leave for two years to Australia from the Bengal Native Infantry (Hodson 1927, p.116); like Arthur Cotton he had been educated at Addiscombe College (Vibart 1894, p.670). Soon after Cotton's arrival he was introduced by Captain Beecher (?Becher) to Elizabeth Learmonth. Later he became engaged to this daughter of a former merchant in Calcutta. Lady Hope also mentioned that her father was a friend of the Franklins and a frequent visitor to Government House.

Arthur Cotton was at first particularly concerned with the performance of a steam engine. The

Madras Government in a public citation of October 1838 recognized his development of a 'rotatory' engine, apparently one of the numerous precursors of Parson's steam turbine (Dickinson 1963, pp.185–92). During an experiment with his engine soon after arrival in Hobart, Cotton was seriously injured by explosion of the boiler; he was then unable to walk for months. He convalesced at first in a hotel, from which he moved to a home on the Derwent a few kilometres out of town. Later he stayed with a family 'in the centre of the island' and then moved to Norfolk Plains (Longford). Cotton returned to India by the expiry of his leave in October 1840.

On Cotton's second visit, he landed at Launceston from the *Nerio* on 6 October 1841. He was married by Rev. John Lillie to Elizabeth Learmonth in her father's house at Green Ponds (Kempton) on 29 October. He had been given leave until October 1842; it was later extended to April 1843. Hope (1900, p.24) did not name a locality where the Cottons lived, but a letter she quoted shows Cotton's intention to take a small farm adjoining a parsonage and to use an engine for irrigation there. Norfolk Plains was apparently the main locality, for that was the address given in Cotton's letter of January 1843 reported in the *Tasmanian Journal of Natural Science* (v.2, no.6, p.76) and that town then had a parsonage, occupied by Rev. R.R. Davies and known as "Pinefield" (Pike 1966–67, v.2, p.143). Captain Cotton left Tasmania with his wife and daughter in time to take up duty again in April 1843.

Cotton's last visit was in 1848–50. He and his family then spent a few weeks in Tasmania before leaving for Victoria in February 1849.

IRRIGATION

An appreciation of Arthur Cotton's contribution to Tasmanian irrigation can be gained by considering its progress before, during, and after his visits. There are many references to this matter in unofficial and official documents or publications made in Tasmania and elsewhere. Hope (1900) only referred briefly to her father's interest in Tasmanian irrigation, in connection with his second visit. The long review by Cotton (1842a) was probably the earliest contribution devoted to irrigation to be published in an Australian colony; it is considered below in some detail. Evidence of Tasmanian irrigation clearly preceding Cotton's arrival is fragmentary and apparently relates only to places near the Derwent River: on the farm reclaimed by Governor Arthur near Bridgewater (Bethell n.d., p.109) and at New Norfolk before February 1836 (Backhouse 1843, pp.348–9).

Cotton's review

Arthur Cotton's paper (Cotton 1842a) appeared in the second and third issues of the journal published by the Tasmanian Society and his first instalment was noted in the *Launceston Advertiser* of 18 November 1841. Cotton, always named A.F. Cotton, was listed as either a corresponding or a resident member (at Norfolk Plains) in early issues of the Journal.

In his paper, Arthur Cotton touched occasionally on what he knew of irrigation as then practised in Tasmania, and gave detailed attention to prospects for extensive irrigation in the colony and the technical measures involved. He mentioned that several landowners in different parts of the island were obtaining better crops of grass and wheat by irrigation and that this practice had also reduced losses due to frost and insect damage. These acknowledgments of existing irrigation compare with those of Bethell (n.d., p.72). concerning irrigation in the 1830s on three properties, and of Burn (1840b).

Prospects for irrigation in Tasmania were considered by reference to topographic, hydrographic, and climatic features of the island. Cotton had 'passed through it (the colony) in various directions' (p.177) and knew Lake Sorell and various streams: the Clyde, Derwent, Jordan, Lake, Macquarie, Russell Falls, and South Esk Rivers. He had not heard in Tasmania 'of an individual river or creek which has not in the upper part of its course a proportionately extensive lake or swamp' (p.84), a situation in marked contrast to southern India. Because of this Tasmanian feature, the provision of a very short bank would allow a large body of water to be collected for release in the dry season. In this connection he mentioned a timber dam seen at the head of the Clyde River, on what he identified as Lake Sorell, and a larger dam on a branch of the Macquarie River.

Arthur Cotton compared the climate of Tasmania with that of Madras, making use of the limited rainfall records for the island and his own estimate of evaporation from Lake Sorell. This led to the conclusion that irrigation would help production over a full year on 120 000 ha of the inland low country (p.85). In his view the Lake River gave the greatest scope for irrigation.

In India, Cotton's irrigation work was concerned with integrated schemes, but his paper in Tasmania shows obvious awareness of the interests of individual landowners, many of whom he found ready to proceed singly with irrigation. He acknowledged that some had already constructed excellent works despite their lack of specialised knowledge (p.179), but others were diffident about the procedure for irrigation (p.181).

Much of the second part of the paper deals with measures for controlling water resources and with alternative means of delivery; by gravitation or by lift using machines powered by steam, bullocks, or wind. One of his last points was the need for state control of water resources, particularly in reference to Tooms Lake in the Macquarie River system.

Personal references at the end of his paper and in the postscript indicate the nature and time of Cotton's consideration of Tasmanian irrigation. Firstly he mentioned his current ailments and his serious accident in the colony. These remarks, consistent with his period of sick leave, show some incapacity for mental and physical exertion; they suggest a contemplative approach to his subject. Secondly, the postscript establishes that the paper was written before the author left Norfolk Plains during his first visit and therefore represented conditions no later than mid-1840.

Projects involving Macquarie River

More than 50 000 ha of low country traversed by the Macquarie River system in the Tasmanian Midlands has an average annual rainfall less than 500 mm (Anon. 1972, p.10), which is often insufficient in summer for crop and pasture growth. The main parts of the upper Macquarie River were first known only as its northern and southern branches, but the former is now identified as the Macquarie River and the latter as Tooms River. That stream drains Tooms Lake, which now covers approximately 600 ha. Long Marsh lies about 10 km to its north, on the Macquarie River.

Efforts to use the water resources of Tooms Lake may have been the first expression of interest in irrigation from the Macquarie. (Gowlland 1980, p.62) mentioned that a weir, 1.5 m high, had been built across the outlet of the lake before 1840, but he did not indicate its purpose — for irrigation or in aid of a water-mill downstream. Cotton's interest in Tooms Lake was shown indirectly and directly in his paper (Cotton 1842a, pp.86, 178). He described the embankment at the lake as 4.5 m high, and gave other details which suggest that he was familiar with it.

Cotton's first visit to Tooms Lake is unlikely to have been before mid-1839. It could have occurred while he was the guest of a family 'in the centre of the island', as his daughter put it, or in the Midlands. While in that region he must have met William Kermode, of Mona Vale, and found that they had a common interest in irrigation. Strzelecki, who lived in Tasmania from July 1840 to September 1842, reported that Cotton helped Kermode with one undertaking involving drainage and another for irrigation which depended on water conserved in a basin on the Macquarie River (Strzelecki 1845, pp.384–5). The details given by that writer concerning the works at that basin agree with Cotton's description applying to Tooms Lake. A beneficial flow of the Macquarie after the opening of the sluice gate at Tooms Lake was reported in the *Launceston Advertiser* of 11 February 1841.

Captain Cotton's interest in Tasmanian irrigation was apparently public knowledge well before his paper was published. In 1840, David Burn — then living in England (Pike 1966–67, v.1, p.112) — introduced Captain Cotton to readers of the London *Colonial Magazine* in his articles on Tasmania. The instalment published in December 1840 states:

> 'The principal source of the Macquarie River is Tooms Lake. This place has recently been surveyed by Captain Cotton ... who reports upon the facility of constructing an immense reservoir ... capable of supplying the wants of numerous flour mills, and of irrigating about 40,000 acres (18 000 ha) during the summer' (Burn 1840b).

There is also the editorial in the *Hobart Town Courier* of 16 April 1841, which is related to the news of February 1841 mentioned above. It states:

> '... owing to the plan adopted of damming the narrow outlet of Toomb's Marsh, as suggested and contrived by Captain Cotton, the stream of the Macquarie has continued to flow most abundantly during the last summer months ...'

The timing of both these statements shows that they concern Cotton's activity during his first visit. Although both reports name the same locality, the associated activities attributed to Cotton are reported differently. The reliability of the account in the Hobart newspaper is not in question, but details in Burn's statement suggest confusion. Thus Cotton did not claim Tooms Lake as the principal source of the Macquarie, and the capability for irrigation that Cotton attached to Tooms Lake is only one-seventh of the area noted above by Burn.

Much informaton has been published concerning the other, abortive effort at irrigation from the Macquarie, involving a large reservoir at Long Marsh. This is the scheme associated by Roberts (1924) with Major (Hugh) Cotton (Pike 1966–67, v.1, p.250), whose involvement is well established. Although Arthur Cotton gave no hint in his paper of a scheme on the Macquarie other than one based on Tooms Lake, it appears that he was involved in the Long Marsh scheme before the arrival of his brother, Hugh Cotton, in Tasmania. A letter from Philip Smith to Mr. Spode, quoted by Gowlland (1980, p.69) reported his return from Tooms Lake

and Long Marsh 'in company with Mr. Kermode, Captain Cotton, and Mr. Jackson'. The date of the letter was given as 13 October 1843, at which time Arthur Cotton was back in India; the original letter is now known to have been written in October 1842 (R.W. Gowlland, personal communication). Arthur Cotton's interest in using Macquarie River water other than from Tooms Lake is reported by Gowlland (1980, p.64) as going back to 1840 and involving an association with landowners in the Midlands. This information suggests that details in Burn's statement above related to Long Marsh, not Tooms Lake.

Other Developments

The success in 1841 of the Tooms Lake scheme helped to focus public attention on irrigation. Sir John Franklin spoke on this matter while in the Midlands later that year, as reported in the *Launceston Advertiser* of 14 October 1841. The *Cornwall Chronicle*, another Launceston newspaper, reported on 9 April 1842 that there was a 'mania for irrigation' and held the diversion of stream water for this purpose responsible for the problems then facing millers dependent on water power. On the other hand, Strzelecki (1845, pp.385–6) was apparently aware of only a few irrigators in 1840–42.

Cotton's intentions of conducting irrigation on a small farm during his second visit (Hope 1900, p. 24) are not confirmed by his later Tasmanian paper (Cotton 1842b), which reported only his development of a steam-driven digging machine.

DISCUSSION AND CONCLUSIONS

Although Tasmania is well watered in comparison with other parts of Australia and has no widespread need for irrigation, there were by the late 1830s some inducements to irrigate, particularly in districts where plant growth is likely to suffer from summer drought. Conditions in the island at the time of Arthur Cotton's first visit were propitious for development of irrigation. The colony was then experiencing an economic boom, largely due to the effects of a serious drought in New South Wales and the establishment of new pastoral runs in Victoria and South Australia (Hartwell 1954, pp.212–5). Secondly, some success with irrigation of crops and pastures had been gained in the colony. Finally, with 26 water-mills in 1829 and 39 in 1839 (Linge 1979, p.130), Tasmanians had gained experience of harnessing the local water resources, and at least in the case of Captain Fenton (Burn 1840a) there was ability to combine milling and irrigation.

Arthur Cotton's influence on Tasmanian irrigation should not be judged solely by reference to his long paper, which — perhaps from modesty, fear of jeopardising his opportunities for long leave on sick certificate, or for another reason — did not fully represent his activities in the colony. His views found a receptive audience. Among it were members of the Tasmanian Society, including Lillie (1842) Strzelecki (1845) and Sir John Franklin; landowners; and some journalists. Cotton's work on behalf of landowners was recognized by the Midland Agricultural Association which, as reported in the *Hobart Town Courier* of 7 January 1842, conferred honorary membership on him, a privilege also extended then to Strzelecki, who had other agricultural interests besides irrigation.

Cotton's expert knowledge, enthusiasm for irrigation, and capacity for communication, contributed to local progress with irrigation. The Tooms Lake scheme, with which he was involved, soon proved an advantage to landowners in the district and its success apparently encouraged others to irrigate in 1842. The persistence of irrigation from Tooms Lake was indicated by Bruni (George A. Brown) in his article on irrigation in Tasmania, in the Melbourne *Australasian* of 3 November 1883. The report by Martelli (1861) shows that by 1860 irrigation had been undertaken on at least 20 estates, some of which then accounted for a total of approximately 250 ha under irrigation.

Strzelecki came to Tasmania at the close of Arthur Cotton's first visit; he showed interest in irrigation though not as an initiator. Hugh Cotton arrived during his brother's second visit, publicised irrigation (Cotton 1843) with extensive reference to his brother's paper, and was involved officially in the Long Marsh scheme. He had considerable experience of Indian irrigation and made plans for extensive irrigation from Long Marsh and other basins (Cotton 1844), but these were abandoned because of financial problems (Gowlland 1980, pp.70–3). Thus there appears to have been no-one in Tasmania who rivalled Arthur Cotton in success with extending irrigation in the 1840s.

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MAMMALS OF THE UPPER HENTY RIVER REGION, WESTERN TASMANIA

by R.J. Taylor, S.L Bryant, D. Pemberton and T.W. Norton[1]

(with 3 tables and one text-figure)

TAYLOR, R.J., BRYANT, S.L., PEMBERTON, D. & NORTON, T.W., 1985 (31:vii): Mammals of the Upper Henty River Region, Western Tasmania. *Pap.Proc. R. Soc. Tasm.* 119:7–14. ISSN 0080–4703. Department of Zoology, University of Tasmania, Hobart, Tasmania 7001 and [1]Forestry Department, Australian National University, Canberra, A.C.T. 2601, Australia.

A mammal survey was conducted in the Upper Henty River Region in western Tasmania. The area had been subject to much disturbance from mining, forestry and frequent fires and was covered by a maze of roads and tracks. Nineteen native species (including bats) were recorded. Four of the species listed in 1983 as occurring in the Lower Gordon Region, 80 km south of the present study area, were not recorded during our survey. It is considered that three of these species would probably have been found in the area with further searching. The fourth species, *Mastacomys fuscus*, is thought not to be present due to increased fire frequency in the sedgeland areas compared with the Lower Gordon Region. *Potorous tridactylus* is recorded for the first time from rainforest. Microhabitat selection by *Rattus lutreolus* and *Pseudomys higginsi* differed from that previously reported. Disturbance from road construction led to the creation of a new food source for *Thylogale billardierii*. The abundance of tracks in the area increased ease of movement for carnivorous mammals. Only one introduced species *Felis catus*, which is also known to occur in the Lower Gordon, was recorded. Disturbance had thus not led to an invasion of exotics.

Key Words: Tasmania, mammals, ecology, habitat disturbance effect.

INTRODUCTION

A survey of the mammal fauna was conducted in the Upper Henty River Region in western Tasmania. The area surveyed is approximately 80 km north of the Lower Gordon Region which had been surveyed for mammals by Hocking and Guiler (1983). In contrast to the Lower Gordon Region, which is relatively undisturbed, the present study area has been subject to a long history of disturbance. Hocking and Guiler (1983) concluded that the hydro-electric power scheme proposed for the Lower Gordon Region would gravely affect the mammal population through habitat disruption and the invasion of exotics. The mammal survey conducted in the Upper Henty Region allowed some of these predictions to be examined.

Hocking and Guiler (1983) described the distribution of mammals in the Lower Gordon Region in relation to structural features of the vegetation. The present study allowed a re-examination of the distribution patterns of the mammals in relation to floristic vegetation categories.

STUDY AREA

The study area is located in the northern part of the South-West Conservation Area (fig. 1). Much of the land in this conservation zone has remained uninhabited and unexploited. The Henty

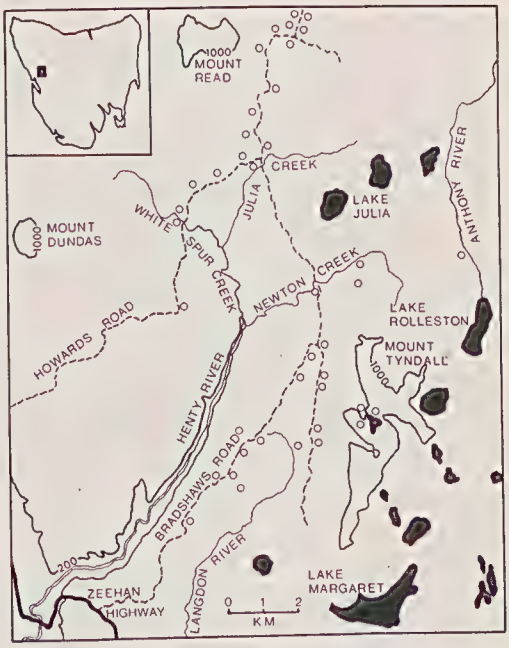

FIG 1. — Map of the study area. The position of trap sites is shown by open circles. Isobars for 200 and 1000 metres are indicated. Only the major roads and creeks are shown.

River area has, however, been subject to substantial disturbance. Mineral exploration in the study area began in the 1880s and has accelerated over the past sixteen years. Many of the roads present were developed by mining companies. A system of grid lines has been cut across the area to facilitate exploration. Two campsites with tin huts are maintained in the area by mining commpanies. Test drilling is being conducted by both the Mines Department and private companies. Selective logging of rainforest followed the development of access into the area and led to the creation of a maze of snig tracks and log dumps (Calais & Kirkpatrick 1983). Prescribed burning, mainly in the sedgeland areas, is conducted regularly by the Forestry Commission. The area is used for recreation by four wheel drive enthusiasts and trail bike riders. Gorse (*Ulex europaeus*), an exotic species, has become established along Howards Road, the most heavily used track into the area. The development of a hydro-electric scheme began in the area after the survey was completed.

Vegetation

Five vegetation types are recognized. These are based on those listed for the area by Kirkpatrick (1977, 1983).

1. Rainforest

Forest or closed scrub dominated by various combinations of *Nothofagus cunninghamii, N. gunnii, Atherosperma moschatum, Athrotaxis cupressoides, Eucryphia lucida, Anodopetalum biglandulosum*. The understorey is usually open with the fern *Blechnum wattsii* and fallen logs being common and mosses covering much of the ground. This habitat encompasses the rainforest, scrub rainforest and mixed forest plant communities of Kirkpatrick (1983). Mixed forest is rainforest with scattered emergent eucalypts.

2. Wet scrub

Closed and open scrub and forest areas which are dominated variously by *Leptospermum, Melaleuca, Acacia* and *Banksia*. The undergrowth varies from dense leaf litter with no shrub layer to dense *Gahnia grandis* or *Restio* sp. with short shrubs being common.

3. Eucalypt scrub

Open-scrub or open-forest dominated by *Eucalyptus* spp. with understories not dominated by rainforest species. Common understorey species include *Gahnia grandis, Bauera rubioides* and *Leptospermum* spp.

4. Sedgeland

Heath or sedgeland with the dominants usually belonging to the Cyperaceae (particularly *Gymnoschoenus sphaerocephalus*), Epacridaceae, Proteaceae, Myrtaceae or Restionaceae.

5. Alpine

Vegetation less than two metres tall composed of austral-montane species. The community consists of a mosaic of cushion plants, dwarf conifers, sclerophyll shrubs and herbs. The alpine area sampled was located on the Tyndall Ranges.

Disturbed areas dominated by *Gahnia grandis* were commonly found along the sides of roads particularly in rainforest. A mat of mosses and sedges was usually present on disturbed soil along the edges of roads and in old log dumps.

METHODS

The main survey was conducted between 6 and 16 November 1983. Four techniques were used to survey the mammal fauna: trapping, direct observation both by day and by night with the aid of a spotlight, analysis of hair samples from hair sampling tubes and from carnivore scats, and indirect evidence i.e. footprints and faeces. A further trapping period for bats and *Antechinus swainsonii* only, was conducted in rainforest between 11 and 21 January 1984.

Three sizes of trap were used for the terrestrial mammals. Elliot type A traps (0.35 x 0.1 x 0.09m), baited with rolled oats and peanut butter were for the small mammals. The middle-sized traps (0.55 x 0.2 x 0.2m) were baited with either apple and peanut butter to attract medium-sized herbivores such as *Potorous tridactylus*, or day old chicks to attract the medium-sized carnivores such as *Dasyurus maculatus*. The larger traps (0.77 or 0.55 x 0.3 x 0.3m), baited with meat scraps, were set to catch larger carnivores i.e. *Sarcophilus harrisii*.

Traps were distributed over the area to obtain replicate samples in each of the different vegetation types. All Elliot and medium herbivore traps were placed off the tracks, inside the vegetation type being sampled. Sixty percent of the medium carnivore traps were placed on the sides of roads or creeks and the rest were placed in the vegetation. All large carnivore traps (except for the one trap in the alpine area) were placed on the side of roads. The location of trap sites is shown in figure 1. The number of traps at each site varied from 2 to 30. Each trap was separated by at least 10 metres but usually more. Most traps were set for eight consecutive nights in the one position. Those in the alpine area and in two of the sedgeland sites were set for three consecutive nights. A patch of hair was removed from animals captured so tha they could be recognized if recaptured. Recapture rates for *Rattus lutreolus* and *Pseudomys higginsi*

TABLE 1

Number of nights each type of trap was set and the number of hair tubes in each vegetation type.

Vegetation Type	TYPE OF TRAP Elliot	Medium Herbivore	Medium Carnivore	Large Carnivore	Bat	Hair Tube
Rainforest	549[A]	35	75	39	66[B]	11
Wet scrub	224	84	32	16	–	2
Eucalypt scrub	294	46	40	38	6	11
Sedgeland	726	6	28	16	–	3
Alpine	207	6	12	3	–	–
Totals	2000	101	187	112	72	27

[A]An additional 355 trap nights with Elliots in rainforest were undertaken during January. These have not been included above as only data on *A. swainsonii* were collected at this time.

[B]11 trap nights during November, the rest during January.

in the different vegetation types were similar, so the analysis of habitat preferences for these two species was based on capture rates and not on the number of individuals caught.

Bats were captured using harp traps (Tidemann & Woodside 1978) placed on narrow tracks. Hair sampling tubes (Suckling 1978), baited with a mixture of rolled oats and syrup, were used to try to detect the presence of small arboreal species which are difficult to trap or observe. Some of the tubes had a funnel glued on to each end to increase the range of sizes of animals able to be detected (Winnett & Degabriele 1982). The tubes were placed on logs or in the branches of trees or shrubs.

The number of trap nights for each type of trap in each vegetation type is given in table 1. A total of 12 hours spotlighting was undertaken: 8 hours from a vehicle and 4 hours on foot. Chance observations of mammals made during the day were recorded as were any footprints or faecal pellets found. Faecal pellets were identified on the basis of reference material and experience gained elsewhere in the state (especially by D.P. with carnivores). The few pellets which could not be confidently identified were not included. Most of the carnivorous mammals caught were kept overnight and any faeces produced were collected. The hair samples from hair tubes and the faecal pellets were identified using the methods of Brunner and Coman (1974).

RESULTS

Species Recorded and Their Habitat Preferences

Monotremes

Tachyglossus aculeatus — Only one animal was seen, on the side of a road in rainforest.

Ornithorhynchus anatinus — One individual was seen in Lake Julia (W. Fulton, pers. comm.). Little time was spent searching for this species and it is likely to occur within many of the lakes and rivers in the region.

Marsupials

Family Dasyuridae

Sarcophilus harrisii — Four individuals were captured, two of which were recaptured. The records for this species for different vegetation types were: rainforest — 4 captures, 2 sets of prints, 2 sets of faecal pellets; wet scrub — 1 capture, 1 set of faecal pellets; eucalypt scrub — 1 capture, 3 sets of faecal pellets; alpine — 2 sets of faecal pellets.

Dasyurus viverrinus and *D. maculatus* — Both species were caught in the large and medium carnivore traps. The number of captures in the

different vegetation types for *D. viverrinus* was rainforest 0, wet scrub 1, eucalypt scrub 3 (all of the same individual), sedgeland 1, alpine 2 (caught in Elliot traps) and for *D. maculatus* was rainforest 3, wet scrub 2, eucalypt scrub 1, sedgeland 0, alpine 0. Three *D. viverrinus*, all on roads through sedgeland areas, were seen during spotlighting and faecal pellets from this species were found in sedgeland and a footprint was found in the alpine area. It thus appears that the two species differ in their distribution among vegetation types with *D. viverrinus* avoiding rainforest and *D. maculatus* avoiding sedgeland and alpine habitats.

Antechinus swainsonii — In January, one juvenile *A. swainsonii* was captured during 355 trap nights in rainforest. No *A. swainsonii* were caught in November.

Antechinus minimus — Only one individual, a female with six pouch young, was trapped. This animal was found in wet closed sedgeland near a small creek. A dense layer of *Melaleuca*, 1.8 metres tall, was present. *Bauera, Sprengelia, Gahnia, Restio*, mosses and lichens were present in the undergrowth. *Gymnoschoenus* sedgelands occurred twenty metres from the trap site.

Family Macropodidae

Potorous tridactylus — One individual was trapped in rainforest and two were seen crossing a road through rainforest. Droppings of this species were also found in rainforest.

Thylogale billardierii — Records for *T. billardierii* (table 2) indicate its presence in all vegetation types. Most individuals were seen feeding near the edges of roads, in clearings or in drainage cuttings where a dense mat of mosses and sedges covered the disturbed ground surface.

Macropus rufogriseus — One individual was seen on a road in an area of wet scrub.

Family Vombatidae

Vombatus ursinus — One individual was seen, during spotlighting, in open sedgeland. The number of sets of faecal pellets recorded in each habitat was: wet scrub 1; eucalypt scrub 5; sedgeland 11 (majority in open areas) and alpine many more than 50. This species was thus most abundant in areas with relatively open undergrowth, especially in alpine vegetation.

Family Peramelidae

Isoodon obesulus — One individual was trapped in closed sedgeland and one individual was seen in open sedgeland.

Family Phalangeridae

Pseudocheirus peregrinus — During spotlighting nine individuals were seen in wet scrub (3 in tall *Banksia* and the rest in groves of tall *Leptospermum*) and three were seen in eucalypt scrub (with *Leptospermum* in the understorey). Two nests were found in tall *Banksia* in wet scrub.

Eutherians

Family Muridae

Rattus lutreolus — *Rattus lutreolus* was the most common and widespread mammal species in the study area. There were significant differences in the density of *R. lutreolus* among vegetation types (table 3: $^2 = 48$, df = 4, $p<0.001$). The density of *R. lutreolus* in rainforest, wet scrub and eucalypt scrub was not significantly different. Population density in alpine areas was low. In eucalypt scrub four captures of two individuals were made in an Elliot trap placed one metre above the ground in a *Banksia* shrub. A sample of *R. lutreolus* hair was also found in a hair tube in a *Banksia* shrub in eucalypt scrub.

For sedgeland, the density of *R. lutreolus* in areas with shrubs 1.3 metres or taller was compared

TABLE 2

Total number of captures and an index of density (number of captures/100 trap nights) for *Rattus lutreolus* and *Pseudomys higginsi* in each vegetation type.

Vegetation Type	*Rattus* No. of Captures	*Rattus* Density Index	*Pseudomys* No. of Captures	*Pseudomys* Density Index
Rainforest	68	12.4	55	10.0
Wet scrub	27	12.1	8	3.6
Eucalypt scrub	47	16.0	10	3.4
Sedgeland	43	5.9	18	2.5
Alpine	1	0.5	1	0.5

TABLE 3
Summary of the status and habitat preferences of each of the mammal species recorded in the study area.

For relative abundance, the greater the number of + the greater were the number of records obtained for the species within that vegetation type. Abundance within a vegetation type is not directly comparable between species. 'Pr' (present) indicates the species occurs in the vegetation type but at a much reduced density compared with other areas. '?' indicates the species may occur in this vegetation type. The platypus (an aquatic animal) is not included.

SPECIES	STATUS WITHIN THE STUDY AREA	RELATIVE ABUNDANCE WITHIN VEGETATION TYPES				
		Rainforest	Wet scrub	Eucalypt scrub	Sedgeland	Alpine
Tachyglossus aculeatus	uncommon	+	?	?		+
Sarcophilus harrisii	common	+	+	++		+
Dasyurus maculatus	common	+++	+++	+		
D. viverrinus	common		+	+	++	++
Antechinus swainsonii	uncommon	+				
Antechinus minimus	uncommon				+	
Potorous tridactylus	uncommon	+				
Thylogale billardierii	abundant	++++	+++	++	+++	+
Macropus rufogriseus	uncommon		+	?		
Vombatus ursinus	common		+	++	+++	++++
Isoodon obesulus	uncommon				+	
Pseudocheirus peregrinus	common		+++	+		
Rattus lutreolus	abundant	+++	+++	++++	++	Pr
Pseudomys higginsi	abundant	++++	++	++	+	Pr
Eptesicus regulus	common	++	?	?		
Eptesicus sagittula	uncommon	+	?	?		
Chalinolobus morio	uncommon	+	?	?		
Nyctophilus geoffroyi	common	+++	?	?		
Felis catus	common	++	+	++		

with that for areas with no shrubs or with shrubs less than 1.3 metres tall. These two types of sedgeland are referred to as closed and open respectively and would be representative of different regenerative ages after fire. Density in closed areas (11.5 captures/100 trap nights) was significantly greater (^{2} = 30, df = 1, $p<0.001$) than in open areas (1.5 captures/100 trap nights). The density of *R. lutreolus* in closed sedgeland is thus similar to that in the rainforest and scrub areas.

In wet scrub, three undergrowth types were recognized. The first type was an open understorey with dense litter present under tall *Leptospermum* or *Banksia*, the second type was a typical eucalypt scrub understorey including *Gahnia, Bauera* and *Leptospermum*, and the third type was similar to the second but with *Restio* replacing *Gahnia* resulting in a more open undergrowth. The density of *R. lutreolus* in these three undergrowth types was not uniform (^{2} = 5.1, df = 1, $p<0.05$). Density in the *Restio* undergrowth (2.1 captures/100 trap nights) was lower than in the litter undergrowth (14.5 captures/100 trap nights) or in the *Gahnia* undergrowth (15.2 captures/100 trap nights).

A dense stand of *Gahnia grandis* was present on the disturbed edge of most of the roads through rainforest. The Elliot traps in rainforest were usually placed near this disturbed edge or occasionally in it. Areas trapped where this disturbance did not occur were above steep road cuttings or in areas isolated from roads. The density of *R. lutreolus* near disturbed areas (14.1 captures/100 trap nights) was significantly greater (^{2} = 6.8, df = 1, $p<0.01$) than for areas not associated with these disturbed areas (3.4 captures/100 trap nights).

Pseudomys higginsi — *P. higginsi* was the second most commonly trapped mammal in the study area. As with *R. lutreolus*, it occurred in all vegetation types but density varied between them (table 3: ^{2} = 51, df = 4; $p<0.001$). The density of *P. higginsi* in wet scrub, eucalypt scrub and sedgeland was not significantly different. Density in

rainforest was nearly three times greater than in the other areas whereas density in alpine areas was markedly less. One individual was captured in an Elliot trap placed above the ground in a *Banksia* shrub in eucalypt scrub.

In sedgeland, density of *P. higginsi* in closed areas (2.8 captures/ 100 trap nights) was not significantly different from that for open areas (2.2 captures/ 100 trap nights). The number of captures in wet scrub was too small for further analysis. For rainforest, the density of *P. higginsi* near disturbed areas (10.6 captures/ 100 trap nights) was not significantly different from that for areas isolated from disturbance (6.8 captures/ 100 trap nights).

Family Vespertilionidae

Trapping for bats was conducted in eucalypt scrub and rainforest during November and in rainforest only during January. No bats were caught in eucalypt scrub. During November three *Eptesicus sagittula* (27/ 100 trap nights) and one *Chalinolobus morio* (9/ 100 trap nights) were caught in rainforest. During January 2 *Eptesicus sagittula* (4/ 100 trap nights), 9 *Eptesicus regulus* (16/ 100 trap nights) and 20 *Nyctophilus geoffroyi* (36/ 100 trap nights) were captured. Two of the same trap sites were used in both November and January. In November no *N. geoffroyi* were caught but in January *N. geoffroyi* were regularly captured at one of these sites.

Family Felidae

Felis catus — Three individuals were caught, one in rainforest, one in wet scrub and one in eucalypt scrub. One animal was seen on a road during spotlighting in eucalypt scrub. Two sets of faecal pellets were found, one in eucalypt scrub and one in rainforest.

The Mammal Community

A total of 19 native and one introduced mammal species were positively recorded in the study area. A summary of the status and habitat preferences for these species within the study area is given in table 3. The number of terrestrial species recorded in each of the vegetation types does not differ markedly (rainforest 8, wet scrub 10, eucalypt scrub 9, sedgeland 7, alpine 6). Most species occurred in more than one vegetation type, however *Antechinus swainsonii* and *Potorous tridactylus* were only recorded from rainforest and *A. minimus* and *Isoodon obesulus* were found only in sedgeland. *Macropus rufogriseus* and *Tachyglossus aculeatus* were also recorded in only one vegetation type. However, based on previous findings (e.g. Green 1973, Hocking & Guiler 1983), it is likely that these two species occur in a wider range of vegetation types.

DISCUSSION

The 19 native species recorded in the study area represent 56% of the indigenous mammal species of Tasmania and 58% if bats are excluded. This compares with the 73% of the mammal fauna (excluding bats) which were found by Hocking and Guiler (1983) to occur in the Lower Gordon region. Four of the mammal species which were recorded from the Lower Gordon region by Hocking and Guiler were not found in the present study area. They are *Sminthopsis leucopus, Cercartetus nanus, Hydromys chrysogaster* and *Mastacomys fuscus*.

Sminthopsis leucopus has been recorded from a wide range of habitats being widely distributed but rare (Green 1973). In Tasmania, factors determining the presence of this species in an area are little understood. The specimens of *Cercartetus nanus* found during the Lower Gordon survey were in pits dug to determine soil profiles (Hocking & Guiler 1983). Green (1973) considers rainforest to be the preferred habitat of *C. nanus*. It is likely that *C. nanus* is present in the study area but not recorded because of the difficulty of detecting this species. Hocking and Guiler (1983) trapped one *Hydromys chrysogaster* on the banks of the Gordon River during their survey. No *Hydromys* were caught by us in the carnivore traps placed beside the major creeks in the area. However it is possible that this species occurs in the larger rivers and the many lakes in the area. In Tasmania *Mastacomys fuscus* occurs mainly in sedgeland (Green 1973). In the Lower Gordon region Hocking and Guiler (1983) recorded three *M. fuscus*, all from an area of mature closed sedgeland which had been last burnt in about 1940. It is possible that suitable habitat for *M. fuscus* does not exist in the study area as the sedgelands are subject to regular firing. Areas of well developed closed hummock sedgeland with emergent shrubs were not found.

The habitat preferences of most of the mammals were similar to that reported by others (e.g. Green 1973, Hocking & Guiler 1983). However, for three species *Potorous tridactylus, Rattus lutreolus* and *Pseudomys higginsi*) habitat preferences differed from those previously reported. *P. tridactylus* has been recorded from sclerophyll forests, low scrub and heathland where a thick ground cover is present (Heinsohn 1968, Johnston 1983). In the present study area it was found only in rainforest. One of the rainforest sites at which *P. tridactylus* was recorded was near other vegetation types but this was not the case for the other two sites. This is the first recording of *P. tridactylus* from rainforest in Tasmania. Its presence in this vegetation type, where ground cover is open, is surprising. No *P. tridactylus* were recorded by Hocking and Guiler (1983) in the Lower Gordon basin.

Rattus lutreolus is predominantly herbivorous and captures have been shown to be correlated with the abundance of monocotyledons, both in Tasmania (Norton 1983) and in Victoria (Braithwaite & Gullen 1978). Since the abundance of monocotyledons in areas of wet scrub containing an open undergrowth with litter is low, the high density of *R. lutreolus* in these areas is unexpected. The low density of *R. lutreolus* in areas of wet scrub with a *Restio* undergrowth, where monocotyledons are abundant, is similarly surprising.

Hocking and Guiler (1983) captured *Pseudomys higginsi* in a wide range of vegetation types in the Lower Gordon region, but only where the undergrowth was devoid of cover within 0.5 m of the ground. *P. higginsi* also occurred in a range of vegetation types in the present study area, however, the undergrowth in which this species was captured covered a range of densities from very open to very dense. The distribution of *R. lutreolus* and *P. higginsi* differed both among vegetation types and with different undergrowth types within the same vegetation type. These differences may be related to differences in the abundance of food present for the two species in each vegetation type. *P. higginsi* probably includes more insects, lichen and bryophytes in its diet than does *R. lutreolus* (Murray 1980, Green 1983, Norton 1983).

This survey of the mammals occurring in alpine habitat is the first reported for Tasmania. Alpine had the fewest number of mammal species of any of the vegetation types in the region. Most of the species found here were also low in abundance. However, based on faecal pellet counts, *Vombatus ursinus* appears to occur at its greatest densities in alpine vegetation. Newsome *et al.* (1983) also report higher densities of *V. ursinus* in alpine vegetation compared with lowland forests in New South Wales. The area of alpine vegetation sampled was small and more extensive surveys of this habitat need to be undertaken, especially in the Central Plateau.

The survey of bats is the first reported for western Tasmania. Four of the eight species of Tasmanian bats were collected in the study area. No bats were captured in eucalypt scrub, probably because of the lack of a suitable flyway situation needed for the harp traps to be effective. *Nyctophilus geoffroyi* and *Eptesicus regulus* have been caught in wet scrub and eucalypt scrub around Melaleuca on Bathurst Harbour (M. Schulz & K. Menkhorst, pers. comm.). The diversity of bats occurring in forests in eastern Tasmania is usually greater than in the present study area (O'Neill 1984).

The larger carnivorous mammals *Sarcophilus harrisii, Dasyurus maculatus, D. viverrinus* and *Felis catus*, were only caught along a road or track or beside a creek despite 40% of the traps being placed in the vegetation. The development of a maze of roads and tracks may thus have increased the ease of movement for these species in the study area. In the Lower Gordon River region, Hocking and Guiler (1983) concluded that *S. harrisii* was confined to areas bordering the major rivers. This was not the case in the present study area where the system of roads and tracks have allowed *S. harrisii* to range more widely. The effect of these differences in movement patterns on the carnivore populations and on predation levels would be worthy of further investigation.

Dasyurus maculatus and *F. catus* were found to have similar habitat preferences and the diet of both species probably consists of birds and small mammals (Edgar 1983, Taylor, unpubl. data). These similarities suggest that competition may be occurring between the two species.

The clearing of vegetation and top soil from along roadsides and in log dumps has allowed a dense mat of sedges and mosses to develop in these areas. The majority of *Thylogale billardierii* seen during the survey were feeding in these moss and sedge areas, which may represent a new source of food for the pademelons. It is not known, however, whether this increased food supply has led to increased numbers of *T. billardierii*.

Hocking and Guiler (1983) warned that disturbance in the Lower Gordon region might lead to the invasion of exotics. Increased disturbance in the Henty Region has not resulted in the permanent colonization of the area by the introduced rodents *Rattus rattus* and *Mus musculus*. Personnel from one of the mining companies reported "mice" to have been abundant in and around the huts at the Julia Creek camp in the summer of 1982. No mice were trapped around the huts during this survey. If these mice were in fact introduced species they have not succeeded in colonizing the native vegetation even in the areas of disturbance.

Those small mammals which utilise sedgelands, *Antechinus minimus, Isoodon obesulus, Mastacomys fuscus*, and *Rattus lutreolus*, seem to prefer closed sedgeland (Hocking & Guiler 1983, this study). In the Upper Henty region, sedgelands are burnt frequently as part of the Forestry Commission's management program. This has resulted in a predominance of open sedgeland with low population levels of these species. *M. fuscus* is an extreme example of this, probably being excluded from the area due to its preference for the very old seral stages of post-fire succession in sedgeland (Hocking & Guiler 1983).

The frequency and intensity of fire in the area will influence the abundance of different successional stages in the vegetation (Jackson 1968,

Brown & Podger 1982). Many of the mammal species in the region have been found to be present only within a restricted range of succession stages (Hocking & Guiler 1983, this study), hence fire frequency will also influence the composition of the mammal fauna. Fire management will thus need to be an important component of any management plan for the South-West World Heritage Area.

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OBSERVATIONS ON DROUGHT DAMAGE TO SOME NATIVE PLANT SPECIES IN EUCALYPT FORESTS AND WOODLANDS NEAR HOBART, TASMANIA

by J.B. Kirkpatrick and F. Marks

(with three tables and five text-figures)

KIRKPATRICK, J.B. and MARKS, F., 1985 (31:vii): Observations on drought damage to some native plant species in eucalypt forests and woodlands near Hobart, Tasmania. *Pap. Proc. R. Soc. Tasm.* 119:15–21. ISSN 0080–4703. University of Tasmania, Hobart, Tasmania, Australia, 7000.

A large number of shrub and tree species suffered damage in the Ridgeway and University Reserves near Hobart, Tasmania during a prolonged drought. Damage was largely confined to shallow soils and gully margins on dolerite, there being little or no damage on equivalent sites on sedimentary substrata. Intraspecific damage was inversely related to the heights of individuals for particular sites. Relative drought resistance is presented diagrammatically for 24 small shrub species and 17 tall shrub and tree species. Drought damage does not directly limit the distribution of most species observed in this study, although the patterns of relative drought resistance accord well with species distribution in respect to available water.

Key Words: Drought resistance, eucalypt forest, eucalypt woodland.

INTRODUCTION

Droughts, although generally unwelcome and destructive, do have some positive aspects. Like fires, floods, freezes and tempests they may provide valuable evidence of the degree and nature of the impacts of environmental factors on species distributions, providing insights almost impossible to attain under controlled laboratory conditions or from field experiment. The relative degrees of drought damage and mortality of intermixed species may provide the opportunity for a definite test of ecological hypotheses based on other evidence. These damage and mortality data may also suggest new hypotheses amenable to testing. Parker (1969) has reviewed some of the northern hemisphere literature on the effects of drought on vegetation. In Australia studies of drought effects on native vegetation include those of Pook, Costin and Moore (1966), Kirkpatrick (1970), Ashton, Bond and Morris (1975), Sinclair (1980) and Hnatiuk and Hopkins (1980).

This paper records the relative damage experienced by a large number of shrub and tree species in the foothills of Mt Wellington, Tasmania during the summer of 1982/83 after several years of drought. The environmental correlates of this damage are also recorded, and the above data are used to test the hypotheses that plant species ranges are limited by uncommon rather than common environmental events, and that the relative distributions of different taxa in relation to available soil moisture reflect relative fitness in relation to drought.

METHODS

Measurement and analysis of environmental variables

Data from the Hobart Waterworks (42° 55'S 147° 17'E, 160 m above sea level) were used to assess the severity of the drought in the period 1976/77 to 1982/83 in relation to mean and medium rainfall for the period 1897–1982.

Soil depth to 0.6m was measured over north-south transects on dolerite, mudstone and sandstone within the Waterworks Reserve, using a soil auger.

Contiguous 1 x 1 m quadrats for plants less than 2 m tall and 1 x 5 m quadrats for plants more than 2 m tall were placed in a transect from the north to the south face of the dolerite hill between the upper and lower reservoirs in the Waterworks Reserve.

All identifiable taxa of higher plants present within each quadrat were recorded. Incident solar radiation for June, December and the year were calculated for the central quadrat of each group of five quadrats using data for slope and aspect and the graphs of Nunez (1983).

Recording and analysis of relative damage

During the autumn of 1983 the Waterworks Reserve and the University of Tasmania property were thoroughly traversed in search for situations where four or more individuals of one species exhibited greater than 10% leaf necrosis and were

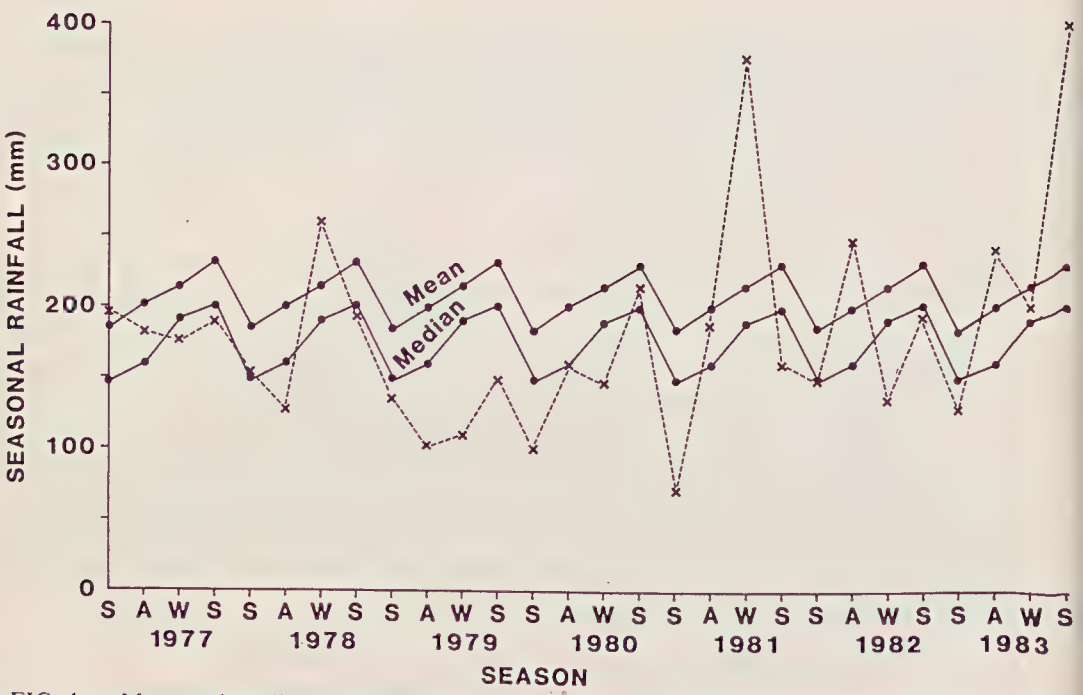

FIG. 1 — Mean and median seasonal rainfall for the period 1897–1982 for the Hobart Waterworks (42° 55'S 147° 17'E, 160 m above sea-level, mean annual rainfall 834 mm, median annual rainfall 819 mm), compared with seasonal precipitation from the summer of 1976/77 to the summer of 1982/83, (---X).

mixed with four or more individuals of another species exhibiting no such damage. The individuals of both species had to be of similar height, and the mixture had to occur within an homogeneous environment, the distance between individuals usually being less than 0.5 m but being up to 6.0 m in the case of a comparison involving badly damaged tall adult individuals of *Eucalyptus viminalis*, and *E. pulchella*. Comparisons were made across slope, upslope and downslope of the damaged individuals, but no species to species comparison was used where the damaged individuals were consistently on shallower soils or upslope of the undamaged individuals.

Randomly located 1 m wide belt transects were placed through mixed species eucalypt regrowth from the 1967 fire. Leaf damage for each individual eucalypt was estimated to the nearest 10% and height was measured to the nearest 0.01 m.

RESULTS

The drought

Eastern Tasmania was one of the regions most severely affected by the drought that commenced in the late 1970's. In the Waterworks area almost all the seasons in the period between and including the autumn of 1977 and the summer of 1982/83 had less than the mean rainfall and most had less than the median rainfall (figure 1). Above average rainfall was confined to two winters and one autumn, and only one summer received between the medium and the mean. The rainfall deficit for this period was 945 mm.

Soils

The soils formed on north-facing slopes on dolerite are generally shallower than those formed on mudstone, which are in turn generally shallower than those formed on sandstone (figure 2). The underlying sandstone and mudstone is also much more broken and permeable than the dolerite bed rock. The measurements of Robinson (1979) showed that the soils formed on dolerite have a finer texture than those on the other two rock types, and hold water at a greater tension for any percentage moisture content.

Vegetation

There is continuous floristic variation from the north to the south facing slope on dolerite

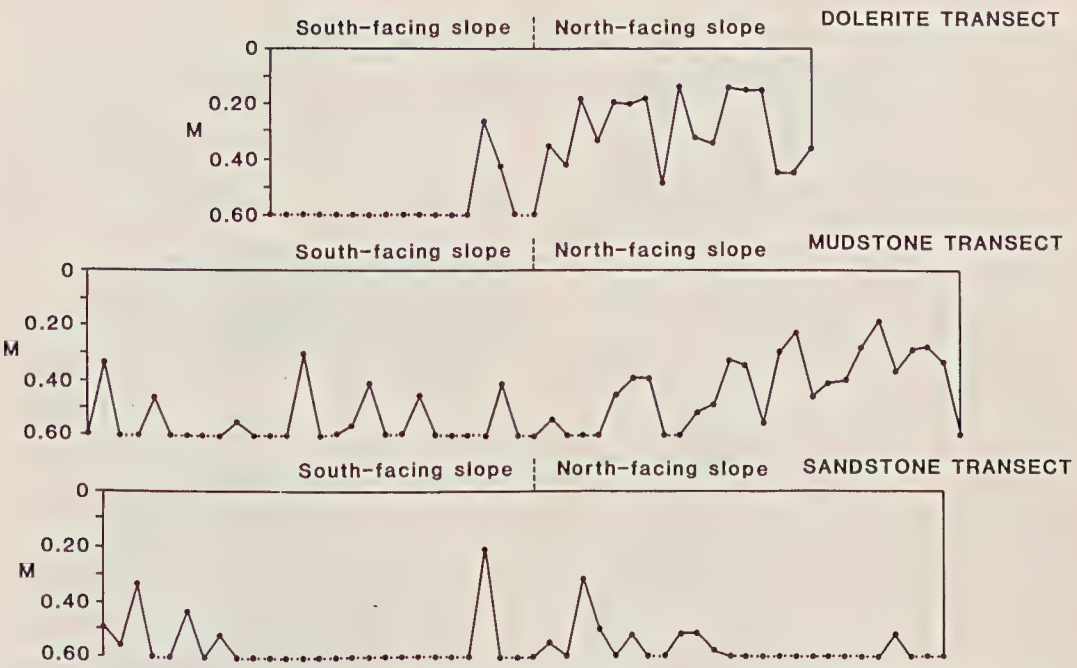

FIG. 2 – Soil depth data along transects across dolerite, sandstone and mudstone hills in the Waterworks Reserve.

(figure 3). Incident solar radiation, and thus moisture availability (Kirkpatrick and Nunez 1980), decreases from the north to the south of the transect.

The locations of damage

Damage and death were largely confined to shallow (< 0.2 m) soils on northerly aspects or to the margins of wet gullies. No species was observed to be drought-damaged throughout its entire environmental range in the area. In fact, damage was almost totally confined to the brown soils formed on dolerite, despite the presence of a similar range of topographic environments on the adjacent podzolic soils on both mudstone and sandstone. Damage was most common where the regrowth from the intense 1967 fire had escaped later biomass reduction burns.

Relative drought damage

Within stands of regrowth eucalypts, the most damaged individuals tended to be the smallest (table 1). Figures 4 and 5 illustrate the relative drought resistance of all tree and shrub species which were observed to occur in an undamaged state in intimate mixture with damaged individuals of another species.

Any species was less damaged than those linked to it by downward lines in the figures. Thus, figure 4 shows that *Bedfordia salicina* was less susceptible to drought damage than all of *Acacia melanoxylon, Leptospermum scoparium, Goodenia ovata, Pomaderris pilifera, Acacia myrtifolia, Epacris impressa* and *Pultenaea daphnoides*. It was more susceptible to drought damage than *Correa reflexa, Dodonaea viscosa, Casuarina stricta* and *Helichrysum scutellifolium*. It may be more or less or equally susceptible to drought damage than the other species in the diagram.

All direct linkages in the diagrams (e.g. *Bedfordia salicina* to *Acacia melanoxylon*, figure 5) have a probability of 0.01 or less of occurring by chance (Fisher's exact test). The indirect comparisons (e.g. *Bedfordia salicina* being less prone to drought damage than *Eucalyptus obliqua* of the same size) are not all supported by direct field evidence (tables 2 and 3). However, they are based on the logical chain that if a is greater than b, and b is greater than c, then a is greater than c.

DISCUSSION

The relative susceptibility to drought damage of the tree and shrubs species included in figures 4 and 5 does largely reflect their relative distributions both in relation to precipitation over their natural range and the more local variations in moisture availability controlled by the varying incidence of solar radiation in hilly areas. For example, seven of the species on the direct line between *Eriostemon*

verrucosus and *Pultenaea daphnoides* in figure 5 were also recorded in figure 3, where they have almost exactly the same distribution patterns that could be expected to result from their relative susceptibilities to drought damage (Spearman's $r = 0.93$, $p < 0.01$). Thus, the species that are least susceptible to drought damage at any particular level of moisture availability do tend to occur on the driest sites, from which the more susceptible species are absent.

Although relative susceptibility to drought damage appears to be a good predictor of geographic range, the direct impact of the drought on species distribution patterns appears to be minimal, dieback being patchy, and seldom complete for any species within a patch. Many species that suffered damage on the dolerite soils were absent from the drier parts of the adjacent sandstone and mudstone slopes, but exhibited no damage in any part of their range on these rock types. No species was damaged over all of its range on dolerite, and many of the species observed to suffer damage did not evince it in the topographically driest part of their range of this substratum. Rather, the damage was manifested where soils were particularly shallow and competition for moisture especially fierce. Biomass reduction burning within the previous half decade prevented any severe drought damage.

Most of the species included in figures 4 and 5 recover vegetatively from fire, and exhibit poor survival of germinates except after fires of high intensity. Thus, distribution patterns are largely fixed by events that occur after severe fires. Individuals establishing after a high intensity fire will be greeted by an edaphic environment with considerably more moisture than would otherwise be the case, because of the severe reductions in transpiration that result from the thermal death of all photosynthetic organs. However, despite the relatively high moisture contents of the post-fire soils, the individual germinate is likely to experience more severe drought stress than at any other time in its lifecycle, as its roots will not have penetrated to the moisture stores at depth, but rather will be within the upper part of the soil where evaporative losses through capillary movement occur. On sites receiving little or no moisture through lateral movement it is only where rock, rather than soil and moisture, is met close below the capillary fringe that an individual plant is likely to encounter more severe stress than occurs in its early days. The death of adult *Eucalyptus obliqua* on the margins of its distribution on relatively deep soil in gullies may occur as the result of the severe reduction in downslope movement of moisture that is likely to occur during warm season drought. In this situation the impact of drought on soil moisture stores is likely to be magnified by a failure of summer rains, as with the drought damaged trees noted by Pook, Costin and Moore (1966) on Black Mountain.

Thus, at least within the study area, the catastrophe of drought is relatively unimportant in fixing shrub and tree species distributions, although patterns of moisture availability are reflected in the species composition of the vegetation.

FIG. 3 – Species distribution and frequency across a dolerite hill in the Waterworks Reserve.

TABLE 1
MEANS AND STANDARD DEVIATIONS OF SEEDLING HEIGHT (METRES) BY SPECIES AND DROUGHT DAMAGE CLASS

	Drought damage								
	0–10%			11–90%			91–100%		
	$\bar{X}$	σ	n	$\bar{X}$	σ	n	$\bar{X}$	σ	n
Eucalyptus pulchella	1.20	0.34	7	0.90	0.27	25	0.78	0.22	13
E. viminalis	1.11	0.41	9	0.78	0.14	9	0.46	0.12	5

Table 2
Relative Drought Damage of Species in the Small Shrub Stratum

Helichrysum scutellifolium (Hs)	Cs, Dv, Cr, Dc, Ah, Bs, Pp
Casuarina stricta (Cs)	Dv, Lv, Ag, Ah, Bs, Pj, Ls, Go, Pp
Dodonaea viscosa (Dv)	Cr, Ag, Bs, Ls, Pd, Pp
Correa reflexa (Cr)	Oe, Bs, Go
Eriostemon verrucosus (Ev)	Hr, Lv, Ag, Ah, Lst, As, Pj
Hibbertia riparia (Hr)	Lv, Ag, Ah, Lst, Du
Dillwynia cinerascens (Dc)	Pj, Ei, Pd, Pp
Olearia ericoides (Oe)	Lv, Pj
Leucopogon virgatus (Lv)	Ag, Ah, Lst, As, Du, Pj, Pp
Acacia genistifolia (Ag)	Ah, Lst, As, Du, Ei, Am
Astroloma humifusum (Ah)	Du, Ls, Ei, Pd, Go, Pp
Lissanthe strigosa (Lst)	Du
Bedfordia salicina (Bs)	Amn, Go
Acacia stricta (As)	Pj, Bm
Daviesia ulicifolia (Du)	Pj
Pultenaea juniperina (Pj)	Amn, Ls, Pd, Go
Banksia marginata (Bm)	
Acacia melanoxylon (Amn)	Ls, Go, Pp
Leptospermum scoparium (Ls)	Ei, Pd
Epacris impressa (Ei)	Pd
Pultenaea daphnoides (Pd)	
Goodenia ovata (Go)	
Pomaderris pilifera (Pp)	Am
Acacia myrtifolia (Am)	

Species shown by name in the first column sustained less damage than those shown by initials in the same row.

Table 3
Relative Drought Damage of Species in the Tree and Tall Shrub Strata

Casuarina stricta (Cs)	Ec, Dv, Ami, Bs, Ad, Amn, Ev, Eg, Ep, Eov, Bm, Ca
Exocarpos cupressiformis (Ec)	Ami, Eg
Dodonaea viscosa (Dv)	Ami, Bs, Amn, Eg, Ep, Bm, Ca
Bursaria spinosa (Bsp)	Bs, Ad, Amn, Ev, Ep, Bm, Ca
Acacia mearnsii (Ami)	Bs
Bedfordia salicina (Bs)	Ad, Amn, Ca, Eo
Acacia dealbata (Ad)	Ev, Ep, Bm, Eo
Pomaderris apetala (Pa)	Amn, Av
Acacia melanoxylon (Amn)	
Acacia verticillata (Av)	
Eucalyptus viminalis (Ev)	Eg, Ep, Bm, Eo
Eucalyptus globulus (Eg)	Oa, Eo
Casuarina littoralis (Cl)	Ep
Eucalyptus pulchella (Ep)	Eov, Bm, Eo
Eucalyptus ovata (Eov)	
Banksia marginata (Bm)	Eo
Olearia argophylla (Oa)	Ca
Cassinia aculeata (Ca)	
Eucalyptus obliqua (Eo)	

Species shown by name in the first column sustained less damage than those shown by initials in the same row.

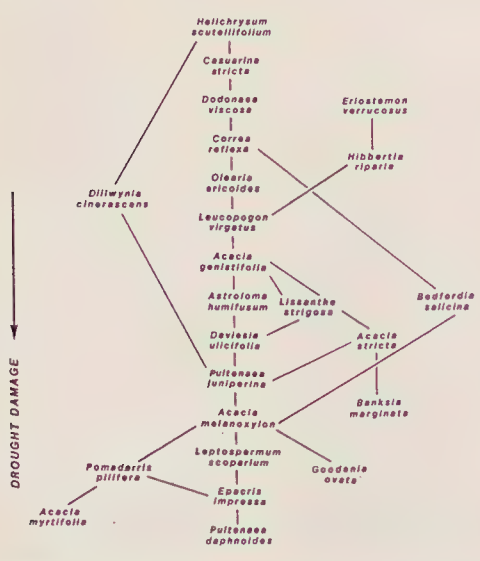

FIG. 4 – Relative drought resistance of shrub species.

FIG. 5 – Relative drought resistance of tall shrub and tree species.

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STRIATIONS ON MINOR FAULTS AND THE STRUCTURE OF THE PARMEENER SUPER-GROUP NEAR HOBART, TASMANIA

by R.F. Berry and M.R. Banks

(with 3 text-figures)

BERRY, R.F. & BANKS, M.R., 1985 (31:vii): Striations on minor faults and the structure of the Parmeener Super-group near Hobart, Tasmania. *Pap. Proc. R. Soc. Tasm.* 119:23–29. ISSN 0080–4071. University of Tasmania, Hobart, Tasmania, Australia, 7000.

Fault striations were measured on 104 minor faults within the Parmeener Super-group near Hobart. The fault striations probably reflect the complex movement history on adjacent large faults. Sophisticated numerical modelling of the regional stress systems which produced these striations indicated at least two phases of faulting. The earlier phase was probably due to compression from the NNW in the Mesozoic and produced strike slip faults striking 100° and 170°. The later phase of faulting was caused by extension towards the ENE in the Early to Middle Tertiary and reactivated most of the early phase faults striking 170°, as normal dip slip faults. A small number of fault striations could not be attributed to either of these events.

Key Words: striations, faults, Mesozoic, Cainozoic, Tasmania.

INTRODUCTION

The Parmeener Super-group (Late Carboniferous to Late Triassic) is a relatively thin (less than 1.5 km) sequence of sedimentary rocks, usually described as sub-horizontal. Rocks of the Super-group were faulted during dolerite intrusion in the Mid Jurassic (McDougall 1961), Evernden & Richards 1962) and during extensional tectonics beginning in the Late Cretaceous (Moore *et al.*, 1984). Banks (1962, pp. 211–213) suggested that all the variation in bedding orientation could not be attributed to fault drag and fault block rotation but support for an independent fold phase has not occurred.

The relationship between faulting, folding, jointing and the geometry of dolerite intrusions remains unclear. We have attempted to clarify these relationships in the Hobart area by studying the distribution and orientation of striations on minor faults. Numerical methods were used to relate these striations to the stress environment at the time of their formation. The stress system is correlated with other structures to generate a coherent view of the structural history of the Parmeener Super-group.

METHOD

A field study of fault striations has not been previously reported from the Parmeener Super-group. Conventional wisdom is that all the faults are related to normal faulting but this has never been convincingly demonstrated. Many of the faults show normal dip slip displacements but in the shallowly dipping beds of the Super-group strike slip displacements are not easily demonstrated.

Fault striations are very common on fractures within the strongly lithified sandy mudstones of the Super-group, especially in the Fern tree Mudstone. The striations were only observed in relatively young excavations, such as roadcuttings, within the sandy mudstones. Only three striations were obtained from any other rock units in this study and they were from calcite-veined fractures in dolerite.

Most of the striations were obtained from faults with less than one metre displacement. The large scale faults in the Parmeener Super-group are seldom exposed well enough for fault striations to be obtained directly. The use of small fractures to identify the regional stress system introduces the possibility of errors due to local stress variations such as with Reidel shears but we have not found any evidence for this type of stress variation in our results. This observation is compatible with the conclusions of Angelier (1984) that the scale of faulting studied does not influence the pattern observed.

Quantitative computer-aided methods for the interpretation of the fault plane striations have been suggested by several authors (e.g. Carey and Brunier 1974, Armijo and Cisternas 1978, Angelier *et al.* 1981, Etchecopar *et al.* 1981). The basic assumptions are that the local stress tensor on the

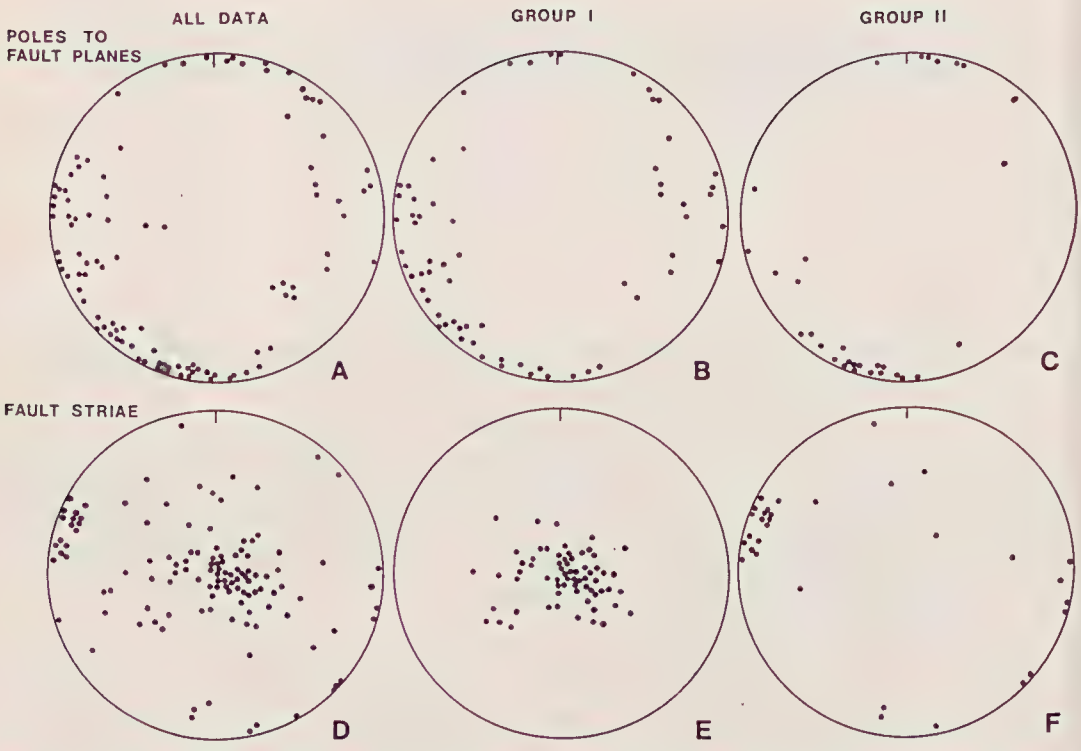

FIG. 1 — Lower hemisphere equal area projection of fault planes and fault striations from the Hobart area. All data collected are shown in A and D while Group I shows all the poles to faults (B) and striations (E) used for solution of extensional stress system and Group II is all poles to fault plane (C) and striations (F) used to obtain NNW compressional solution.

fault plane is parallel to the regional stress tensor and that the direction and sense of slip is parallel to the maximum resolved shear stress direction on the plane. We have developed a set of computer programs of the type described by Etchecopar *et al.* (1981) and using IMSL library routines to find the stress tensor compatible with any set of fault striations.

The numerical method can be worked in two directions. The program "STRIA" finds the stress tensor which has the lowest sum of the squares of angular errors between the predicted and measured striations direction for each plane. Where striations from more than one event are included, outliers are eliminated automatically. The second program "STRIA/TEST" starts from a predicted stress tensor and looks for the nearest stress tensor which is an exact fit to each of the fault striations measured. This provides a useful test of the stability of the solutions obtained. Both these programs are as described by Etchecopar *et al.* (1981) except that they do not attempt to predict the sense of motion. This limitation was made because we do not have a reliable measure of the sense of motion for 95% of our fault striations. This leaves an ambiguity in the stress tensor which we resolved by consideration of qualitative data.

FAULT STRIATIONS

The fault striations were collected in two groups. The first 80 striations were analysed and then we collected a further 43. No significant changes occurred in the overall result due to this addition which suggests this is a representative sample for the Hobart area. All the fault plane and striations orientations are shown in fig. 1. The faults are mainly steeply dipping and include all strike directions. The E striking faults are all nearly vertical, suggesting a strike slip origin which is confirmed by the large number of horizontal fault striations amongst this group. The N striking faults have more variable dips but are mainly steep, suggesting both normal and strike slip faults. The majority of striations on these faults indicate dip slip motions. Where the sense of motion could be determined these faults had a normal sense of displacement. The NE striking faults have only

FIG. 2 — Fault striations and fault plane orientations for four localities east of Hobart:- A. Tunnel Hill, B. Cambridge, C. north of Geilston Bay, D. Risdon Brook Dam. Location map in inset. Fault locations from Leaman (1972b).

moderate dips. Few near vertical faults of this strike were observed, in contrast to all other strike orientations.

The entire data set was tested using "STRIA". The method produced two groups of faults, one predominantly composed of dip slip faults and the other predominantly transcurrent faults. In each case the stability of the solution was checked using "STRIA/TEST" and the groups modified accordingly.

The largest group of fault striations (68) are shown in fig. 1E. The inferred stress system is compatible with the normal sense of slip observed on seven of these faults. The maximum compressive stress (σ_1) was near vertical and the two other principal stresses (σ_2,σ_3) nearly the same so that no specific extensional direction can be recognised from the striations. The method gave a slight support for extension to the NE. The orientations of faults in this group are not easily related to these stress directions. We conclude that most of these faults occur along fractures which predate the extensional event.

The second group of 34 fault striations recognised is shown in fig. 1F. The solution obtained by "STRIA" was compression from the NNW (330°) in a triaxial stress field where σ_2 was vertical. The solution was poorly defined with an estimated accuracy of ± ten degrees. In this case we have no direct evidence that the correct solution is compression from the NNW, rather than extension towards the NNW but circumstantial evidence discussed later supports the former solution.

Of the 21 fault striations not represented in these solutions six are poor fits to the second solution and the remaining 15 do not fit either group and do not themselves represent a coherent additional group.

The attempt to model all the striations data in one group assumes a constant regional stress system. In the Hobart area, this may not be an accurate assumption as local variations could be produced by the contrast in rheology between dolerite and the Parmeener Super-group, topography at the time of faulting, and pre-existing fault and joint surfaces. There is sufficient data from six localities to allow independent assessment of the fault striations. The consideration of these small areas, separately, minimizes the problems due to local fluctuations in the stress field.

Forty one fault striations were recorded from Tunnel Hill, Tasman Highway (fig. 2, location A). There are two easily recognisable groups of faults in this area. In the northern part of the outcrop strike slip faults striking 090° to 120° are most common. Five fault planes dipping at 45° to the NW occur at the southern end of the exposure and a nearby large scale fault with the same strike shows a northside up motion (Leaman 1972b). This

field relationship strongly suggests a reverse motion on these faults. Both these fault sets are compatible with compression from the NW. The expected set of conjugate strike slip faults may be represented by steeply dipping faults striking 290° to 020° which, however, now have predominantly dip slip striations. In one case the dip slip motion on one of these faults disrupts strike slip striations.

STRIA was applied to both these groups.

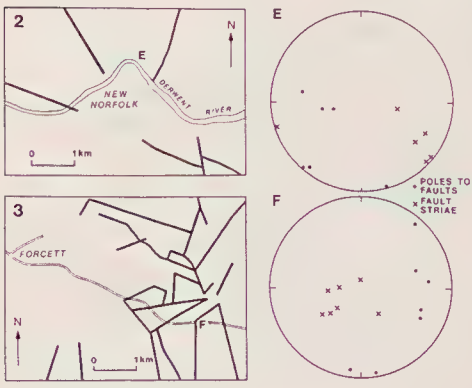

FIG 3 — Fault striations and fault plane orientations for localities E (New Norfolk) and F (Forcett). Location of maps shown on Fig. 2. Faults shown are from Leaman (1972b) and Gulline (1982).

The former group gives a moderately successful solution compatible with compression from the NW (σ_1:0/303; σ_2:85/033; σ_3:5/213; $(\sigma_2 - \sigma_3)/(\sigma_1 - \sigma_3) = 0.4$).

This solution is rotated 24° anticlockwise from the average solution for the whole area. The latter group of fault striations gave a solution with the extension to the ENE (σ_1:50/219; σ_2 :9/319; σ_3:39/56; $(\sigma_2 - \sigma_3)/(\sigma_2 - \sigma_3) = 0.7$). While the calculation was stable for any given selection of faults in this group, the application of STRIA/TEST suggested there was little difference in the closeness of fit between NE and E extension directions from this data.

One kilometre to the NE, locality B, 14 of the 16 fault striations are compatible with normal fault motion on faults dipping 80° to the ENE and 60° to the WSW. The two remaining striations were probably formed by NW compression. The low proportion of striations due to the latter stress system implies this area is distant from large scale strike slip faults but the dominance of very steep fault planes implies that many of the extensional faults occur on pre-existing fracture surfaces.

The dip slip fault at this locality were analysed using STRIA. The 14 fault striations fit a stress field which is extensional in all horizontal directions (σ_1:67/091; σ_2:0/182; σ_3:23/272, $(\sigma_2 - \sigma_3)/(\sigma_1 - \sigma_3) = 0.1$). No preferred extensional direction was found using STRIA/TEST.

At locality C, 2 km north of Geilston Bay, there are both strike slip and dip slip striations, often on the same fault plane. Most of the faults, with near horizontal striations, strike 345° in contrast with locality A but subparallel to the nearest large fault (fig. 2). Many of these faults also have steeply pitching striations. Some of them have two steeply pitching striations about 20° apart indicating a complex stress history. Using STRIA/TEST the fault striations are compatible with extension to the E or NE.

At the Risdon Brook Dam, Locality D, both strike slip and dip slip faults were observed. The strike slip faults strike 280° and are subparallel to the major fault to the north. This large fault may have a large strike slip component which is predominantly pre-dolerite, based on the pattern of faults shown for this area on the Hobart sheet (Leaman 1972b). There is one possible conjugate strike slip fault striking 320°. All but two of the dip slip faults have strikes between 320° and 010°. The most common strike is 330° and this is subparallel to the large fault to the east (fig. 2). STRIA gave an unstable solution to the steeply pitching striations with a preferred extensional direction towards the NE. STRIA/TEST was also ambiguous and no preferred extension direction was determined.

The remaining two locations are further from Hobart and both have the minimum possible data for a stress analysis. Locality E, near New Norfolk, has a simple pattern of striations which is possibly the result of a single event. Strike slip faults strike 070° and 130° suggesting conjugate shears (fig. 3). The remaining faults have low to moderate dips. The sense of motion on thee faults could not be determined but joints of the same orientation showed "en passant" relationships (Kranz 1979, Swan & Hagan 1978) indicating a normal sense of shear. STRIA gives a good fit to these six faults with extension to ESE (σ_1:5/189; σ_2:89/009; $\sigma_3$0/099, $(\sigma_2 - \sigma_3)/(\sigma_1 - \sigma_3) = 0.7$). The general fault pattern here, and the calculated stress, is compatible with the extensional events. This includes some strike slip faults and suggests some of the strike slip motion on E-W faults may be related to the extension. With the small data set available at New Norfolk this result remains provisional.

Near Forcett, locality F (fig. 3), there is a wide variety of fault orientations but all of them have steeply pitching fault striations. The faults are all compatible with normal faulting and extension towards the NE. Assuming all the striations were produced in a single event, STRIA gave a stable solution with near vertical compression and $\sigma_2 \cong \sigma_3$ so that the extensional direction is not well constrained (σ_1:65/185, σ_2:24/024, σ_3:7/291, $(\sigma_2 - \sigma_3)/(\sigma_1 - \sigma_3) = 0.1$). The large scale fault pattern near this locality shows a N striking fault to the W and a NE striking fault to the N. Both of these orientations are reflected in the fault striations. From our data both fault orientations have 60° dips to the W compatible with the W side down and normal motions implied for the large scale faults (Gulline 1982).

Throughout the preceding discussion we have chosen the most likely of two stress systems which are possible for any given set of fault striations where the sense is unknown. In the case of the faults showing extension to the E and NE there is sufficient direct evidence of normal motion to support this model but in the case of compression from the NW the evidence is indirect and less definite.

The presence of faults dipping moderately NW is suggestive of a compressional regime. The angle between strike slip faults is usually acute in the NW quadrant which indicates this is the direction of maximum compressive stress assuming Anderson's (1951) model for strike slip faulting.

On the Hobart map sheet (Leaman, 1972b) there are several examples of probable right lateral displacement on faults striking 100° (Risdon Vale — Australian Map Grid Zone 55, coordinates 527/618, 528/605) for which our analysis supports a strike slip motion. In combination these features support the interpretation of NW compression over the alternative NW extension.

DISCUSSION

Local Significance.

The movements indicated by fault striations on minor faults support a direct interpretation of the large scale fault pattern near Hobart. East of Hobart the most common fault orientations are striking 100° and 170° (fig. 2). From our modelling we conclude these probably formed originally as strike slip faults related to NW compression. The fault pattern in Risdon Vale area fits a right-lateral motion on the faults striking 100° and strongly suggests much of this motion predates the dolerite intrusion forming Mt. Direction. The NE striking faults to the north of Risdon Vale are inferred to have reverse motion as is the small NE striking fault SE of locality A. The pattern of faults in this area is similar to the experimentally derived pattern of strike slip faults discussed by Freund (1974, fig. 18). He interprets this pattern as the result of sequential development of conjugate faults each of which offsets and locks the pre-existing faults.

The extensional faults reported in this study are highly variable in orientation and there is no obvious correlation with the inferred stress direction. In several locations conjugate sets of normal faults exist where one of the sets dips at 60° while the other dips at 80° or steeper. Since the extensional faults are probably later (see below) we interpret this as reactivation of steep fractures of suitable orientation which are inherited from the NW compression, and formation of new fractures with dips of approximately 60° where no suitable fracture orientation were already available. The extensional direction of this event is not well constrained. Features such as the Derwent Graben suggest extension to the ENE. The fault striations we have analysed indicate extension to the NE, E or even ESE. One extra piece of information is effectiveness of reactivation of faults which are presumed to have formed during the NW compressional event. Most of the steep N striking faults are reactivated during this phase but less than half of the steep E striking faults have been reactivated. This strongly supports the conclusion that the main extensional direction was between NE and E.

Relative age of the two fault systems.

There are several lines of circumstantial evidence that the major extensional event postdates the NW compression. Firstly the dominant fault pattern in the Parmeener Super-group can be interpreted using the Anderson (1951) model for faulting and assuming the faults formed by compression from the N.W. The near vertical faults striking N and E are potential strike slip fault directions at less than 45° to the compression direction where σ_2 is vertical. The small number of low to medium dipping planes striking NE are possible reverse fault orientations. These orientations include the vast majority of faults in the Parmeener Super-group near Hobart. In contrast NW to N striking faults with 60° dips are a minor component of the faults recorded in this study.

Secondly, the striations on fractures presumably active during both phases of tectonism, are dominantly of extensional origin suggesting the obliteration of earlier shallowly pitching striations. In one case a fracture with both orientations of stria showed evidence of partial obliteration of the shallowly pitching stria.

Finally, dip slip motion was dominant in the

formation of the present Derwent Graben. In contrast there is little evidence that strike slip faults have disturbed the present topography. Therefore we conclude that the NNW compressional event occurred before the NE extension.

Regional implications

The complexity of faulting in the Parmeener Super-group has been recognised by a number of authors. For example Leaman (1972a) recognised three phases of faulting in the Hobart area. A Jurassic event with N–S grabens, an Eocene event with NNW striking normal faults and finally a latest Tertiary rejuvenation with NW strikes most common The significance of strike slip movement has not been recognised in this or other studies of faulting in the Parmeener Super-group.

Forsyth (1984) collected very detailed information on the relationship of faulting to dolerite intrusion in the Oatlands area. He showed conclusively that the orientation of faults active before dolerite intrusion was very similar to that of faults active after the intrusion. Since we have concluded that this fracture pattern was generated by NNW compression, this phase of faulting was active before the Mid Jurassic. In the Risdon Vale area the dolerite is also offset by these faults and near Tunnel Hill there are faults thought to be of this type cutting the dolerite. These facts imply that the same stress system continued during or after dolerite intrusion.

The extensional tectonics in Hobart region produced the Derwent Graben. Since Palaeocene microfloras have been recorded from this area (Harris 1968), the extensional tectonics began in the Early Tertiary. Thus the provisional data on the relative age of faults in the Hobart area fits the regional structural relations.

The relationship with Victoria and Bass Strait is less clear. Davidson *et al.* (1984) summarize the structural data from the Bass and Gippsland Basins. They date the extensional phase of faulting as Upper Cretaceous to Middle Eocene in agreement with data from the Derwent Graben. They also recognise reactivation of these structures as strike slip and reverse faults in the latest Eocene to Recent with most activity in the Middle Miocene. Further evidence for NNW compression in the Late Tertiary occurs onshore in Gippsland (Barton 1981) where normal faults have been reactivated as reverse faults and produced draping in Late Tertiary sediments. This stress system probably continues to the present (Worotni & Denham 1976) although seismic evidence is equivocal (Denham *et al.* 1981).

Active strike slip and reverse faulting in the Late Tertiary of Bass Strait, suggests similar motions should have occurred in the Hobart region. With the complexity of faulting and limited data in this area, we have not been able to separate out fault striations of this age from the group produced in the Mesozoic. The weight of evidence near Hobart is that the fault striations related to NNW compression are predominantly of Mesozoic age but we cannot exclude the possibility that a substantial proportion of them formed in the Late Tertiary.

CONCLUSIONS

The movement history of the faults within the Parmeener Super-group is preserved by fault striations on small faults and fractures near them. Several major faults within the Group have had strike slip motion before the extensional, normal motion which produced the Derwent Graben. Close attention to the fault striations, combined with sophisticated numerical modelling, indicates the stress system at each stage of the fault motion. This data can be combined to generate a coherent model of the tectonic history of the Group near Hobart.

A major NNW compressinal event in the Mesozoic established a fracture pattern with strike slip faults striking 100° and 170°, and reverse faults striking NE. This event was active before and after the intrusion of dolerite in the Jurassic. A subsequent phase of faulting, Early to Middle Tertiary, produced the Derwent Graben by general E to NE extension predominantly by reactivation of faults established in the Mesozoic. The nature of Late Tertiary faulting remains in doubt.

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(accepted Feb 21, 1985)

DEFENSIVE STRATAGEMS OF PLANTS, WITH SPECIAL REFERENCE TO ALLELOPATHY

by J.V. Lovett

(with three tables and two text-figures)

LOVETT, J.V., 1985 (31:vii): Defensive stratagems of plants, with special reference to allelopathy. *Pap. Proc. R. Soc. Tasm.* 119:31–37. ISSN 0080–4703. Department of Agricultural Science, University of Tasmania, Hobart, Tasmania, Australia, 7005.

The green plant has evolved an array of defences to ameliorate the effects of stresses in its environment. Allelopathy, biochemical interactions between plants, plays a role in plant defence but recent work suggests that some compounds which act as allelochemicals may also be effective in the defence of plants against other organisms. Some examples of allelopathy in associations of crop and weed species are discussed in this context.

Key Words: allelopathy, trichome, plant defence

INTRODUCTION

The advantage to the green plant of autotrophy is to some extent offset by the disadvantage of a static habit in an often hostile environment.

In the more mobile animal kingdom physical and chemical defences against environmental stresses are well developed and widely recognised. This suggests that an array of defensive ploys by plants will also occur but such ploys have attracted relatively little attention in the literature.

A first line of defence is the plant surface which, although relatively tough, may be damaged by the elements, by pollution, by abrasion and by a variety of organisms. The waxy cuticle of leaf surfaces may act as a primary barrier to attack by a variety of organisms (Cutter 1976) and many leaves also carry trichomes which contribute to the defence of plant surfaces (Levin 1973). Trichomes may, for example, deter insects from landing on leaves or mammals from eating them. Tobacco trichomes are known insect-repellents (Thurston, Smith & Cooper 1966) whilst other species, such as nettles, have developed the trichome to a high level of defensive sophistication as "syringes" which deliver irritant chemicals when the tip is broken (Fahn 1967). However, whilst the physical significance of structures such as trichomes in a defensive mode has been recognised, the complementary role of plant-produced chemicals has been much less explored.

SECONDARY COMPOUNDS AND PLANT DEFENCE

Chemicals are frequently employed in the defence of animals (Edmunds 1974) even when physical defences are well developed. Thus, in the Australian turtle genus *Chelodina* the protection afforded by the shell may be complemented by malodorous fluid when the animal is alarmed (Cogger 1979), whilst in savannah ungulates (Gosling 1980) inter-specific scent communication may assist in the formation of a "defence guild".

In plants, chemicals used in a defensive mode are by-products of primary metabolic pathways and are known, accordingly, as "secondary compounds" (Levin 1976). Amongst the groups of secondary compounds, the phenolics, waxes and terpenes are widely distributed among plant families whilst other groups, for example, the glucosinolates found in the Brassicaceae, are particularly identified with a single family. Although qualitative and, more particularly, quantitative, information on these chemicals is often lacking, they are recognised as widely distributed and normal products of plant metabolism.

ALLELOPATHY

A field of study in which the role of secondary compounds is currently of considerable interest is allelopathy. The term means, literally, "mutual harm", and it has been applied in this sense to negative, or inhibitory, chemical interactions between plants. However, depending on concentration, allelochemicals may stimulate biological responses (Lovett 1982a). Thus, Molisch (1937) extended the term "allelopathy" to include all chemical interactions, whether positive or negative, between plants of all levels of complexity. This broader definition has gained wide acceptance and more recently (Lovett 1982a, 1983a) it has been recognised that chemicals studied in the context of

Aspects of three case studies are presented to illustrate the range and complexity of allelopathy, as demonstrated by weeds and in the context of defensive strategems.

The association of *Camelina sativa* (L.) Crantz and *Linum usitatissimum* L. (linseed)

Camelina sativa (Brassicaceae) has been recorded as a weed of cultivation in Western Australia, South Australia, Victoria and Tasmania (Hewson 1982). It is better known as a weed of *Linum usitatissimum* (Linaceae), linseed, in European cropping systems where work of Grümmer and Beyer (1960) indicated that the yield of linseed could be significantly reduced in the presence of *Camelina* spp. in the field if rain fell at a critical time of the year. Rain washed chemicals from the leaves of the weed onto the leaves of the crop, promoting the phytotoxic effect. Although this report aroused considerable interest, like many other instances of allelopathy further investigations were neglected. Thus, the chemical, or chemicals, concerned were not identified nor was the primary mode of action of the weed-produced chemical on the crop plant elucidated.

Through a series of experiments commenced in 1977 a more complete understanding of this interaction has been gained (fig. 1).

Under controlled conditions washings of intact foliage of *Camelina* consistently stimulated the growth of the radicles of germinating linseed seeds. The presence of bacteria in the *Camelina* phyllosphere was necessary to the stimulatory phenomenon. These were cosmopolitan, gram-negative rods, *Enterobacter cloacae* (Jordan) Hormaeche & Edwards (Lovett & Sagar 1978) or *Pseudomonas fluorescens* (Trevisan) Migula (Lovett & Jackson 1980).

Washings of *Camelina* leaves contain organic acids which sustain rapid bacterial growth. During this growth, complex organic compounds present in the leaves are broken down to simpler compounds at least one of which, benzylamine, is allelopathic (Lovett & Duffield 1981). Leaf damage may be necessary to the release of the precursor, benzyl isothiocyanate, and as maximum bacterial populations are present in senescent foliage (table 1), maximum allelopathic activity may occur at this stage of the life cycle.

In petri dishes, under controlled conditions, benzylamine at low concentrations stimulated germinating seedlings of linseed in a manner similar to that produced by *Camelina* leaf washings. Higher concentrations became inhibitory, a response typical of allelochemicals (Lovett 1982a). However, in soil under controlled conditions, even

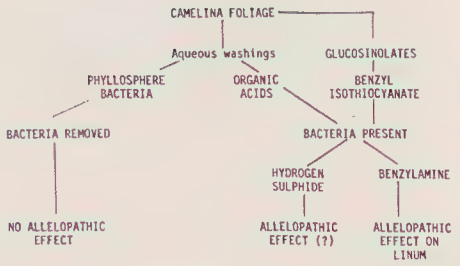

FIG. 1 — Allelopathy in a *Camelina sativa*, phyllosphere bacteria and *Linum usitatissimum* association.

allelopathy may play a wider role in the defensive and, possibly, offensive relationships of plants.

In natural plant communities allelochemicals are among the factors which maintain homeostasis (Rabotnov 1981). Many responses to allelochemicals are, therefore, subtle, having developed during evolution of plant communities. Continuing the analogy with animal responses Edmunds (1974) states, in relation to communities of animals, "... there will be much greater selection pressure to evade predation and to evolve highly elaborate anti-predator defences in a stable environment than in an unstable environment".

Allelopathy is a part of "interference", the term used by Harper (1977) to describe changes in the growth rate and form of plants brought about by the influences of neighbouring plants upon the environment. Competition for environmental resources, commonly, light, water and nutrients (Donald 1963), is also a part of interference. Conventional agricultural practise maintains disturbed (unstable) environments with restricted species diversity. In such environments weeds are often able to express their capability to interfere with other plants to a greater extent than occurs in species-rich, stable communities. Thus, competition and allelopathy may become more readily apparent.

Crop plants tend not to be allelopathically active, especially when highly selected (Lovett 1983b). Where weed and crop species are close relatives the former show the greater allelopathic potential (Lovett, Fraser & Duffield 1982). Since there is an energy cost to the plant in producing secondary compounds (Levin 1976) it may be that selection for physiological specialisation in the direction of quantity and quality of yield militates against the development of an endogenous chemical defence capability in crop species. Conversely, in weeds, this capability can be better developed without detriment to other attributes.

Table 1
Bacterial colonies developed from similar volume samples of washings from *Camelina* foliage after 24h incubation (colonies per 9cm diameter plate, means of four replicates).

	Senescent leaves	Green leaves	Flowers/immature capsules	Stalks
Number of colonies	854[a]	7.0[b]	5.3[b]	0.75[c]

Means which are identified by the same letter are not significantly different at the 5% level, Studentized Range Test. (After Lovett 1982b).

low concentrations of benzylamine proved to be inhibitory to germinating linseed (table 2). It seems likely that the more complete and sustained contact between seed and soil compared with seed and filter paper in a petri dish leads to a greater uptake of benzylamine with consequent inhibition rather than stimulation.

Transmission electron microscopy (TEM) has indicated disruption of cellular membranes and suggests that the primary cause of reduction in early growth of linseed seedlings is a reduced ability to metabolise food reserves (Lovett 1982b). Such fundamental disruption could be significant at other growth stages where metabolic activity is high, for example, seed filling. In addition, it has been observed that benzylamine creates hydrophobic conditions in soil, possibly inhibiting uptake of water by plants (Lovett 1982b).

In this particular example the definition of allelopathy by Molisch (1937) is amply justified through the combination of a bacterium modifying a chemical exudate from one higher plant to a form which becomes potentially phytotoxic to a second higher plant.

The involvement of bacteria as intermediate organisms in promoting allelopathy appears to be unique in the literature. Other organisms may, however, play a complementary role. For example, Trenbath and Fox (1976) have suggested that phytophagous insects concentrate allelochemicals produced by leaves of *Eucalyptus globulus* s.sp. *bicostata* (Maiden *et al.*) Kirkp. Whilst aqueous washings of *E. globulus* leaves slightly encouraged germination of sensitive pasture species in their experiments, insect droppings, in which allelochemicals were concentrated, became inhibitory. These findings parallel our experience with bacteria in the *Camelina*/linseed system.

In correlating these observations with the data of Grümmer and Beyer (1960) the importance of water in allelopathic systems becomes apparent. In their experiments rainfall in the field at a critical time of year was necessary to the allelopathic manifestations and our data suggest that this time corresponds to the maximum release of substrate by the weed and, perhaps, to particular vulnerability of the receiving crop.

The association of *Datura stramonium* L. and *Helianthus annuus* L. (sunflower)

Whittaker (1970) states that alkaloids are "... evolutionary expressions of quiet antagonism of a

Table 2
Effects of benzylamine on early growth in soil of *Linum usitatissimum* (means of ten replicates).

Variables	Days after sowing	Benzylamine (ppm) 0	10	100	1000	P
Radicle length (mm)	8	167.0[a]	148.8[ab]	137.9[b]	108.0[c]	< 0.001
Shoot height (mm)	7	23.4[f]	23.1[f]	21.4[g]	20.7[g]	< 0.01

Means which are identified by the same letter are not significantly different at the 5% level, Studentized Range Test. (After Lovett and Levitt 1981).

plant to its enemies". However, whilst many studies have been made of the effects of alkaloids upon mammals, including humans, there is a dearth of information as to the effects of alkaloids produced by plants upon other plants.

The family Solanaceae is particularly associated with alkaloid formation, many species having a history of use in pharmacy and other purposes. *Datura stramonium* is an important weed member of the family, present in all Australian States (Purdie, Symon & Haegi 1982), which adversely affects the growth of, particularly irrigated summer crops in areas such as northwestern New South Wales (Felton 1979). *Datura* is known to contain a number of alkaloids, principally scopolamine and hyoscyamine (Mothes 1955). These are translocated from the site of synthesis in the roots to accumulate in the leaves and seeds (Cromwell 1944, Dawson 1948). The leaves are unpalatable to stock as a consequence of their bitter taste but other implications of the alkaloid content for plant defence have remained unexplored.

The presence of the alkaloids scopolamine and hyoscyamine in aqueous washings of *Datura* foliage and seeds has been confirmed (Lovett, Levitt, Duffield & Smith 1981), with washings of seeds containing higher concentrations of the alkaloids. In two sterile media the presence of 4.95g *Datura* seed, the average contents of one seed capsule, in 50ml sterile water, significantly reduced radicle length of sunflower (table 3). Further studies (Levitt & Lovett 1984) in which different soil types were used, indicated that the type and amount of clay, the amount of organic matter and the dominant particle size of the soil all modified the allelopathic effect (table 3).

Under controlled conditions, alkaloids from *Datura* seeds remained at concentrations which were toxic to germinating seeds of sunflower for over 35 weeks in lateritic podzolic soil. These effects had both chemical and physical components, with the moisture status of the soil influencing the magnitude of the inhibition.

Under field conditions, the phytotoxicity of *Datura* allelochemicals persisted in lateritic podzolic soil for 15 weeks.

During the course of these experiments a property at Moree (northwestern New South Wales) was visited where an irrigation farmer had experienced three consecutive failures with different summer crops. The black earth soil on the property had a history of severe infestation by *Datura*. Thin layer chromatography was used to identify the alkaloids, scopolamine and hyoscyamine, from the soil where they had been present for up to 7 months.

Dormancy is an important factor in dispersal in time of many species of weeds. In *Datura*, dormancy is broken when alkaloids are leached from the seed coat. Rain is vital to this process. Following rain, or pre-irrigation, crop seeds adjacent to *Datura* seeds in the soil are exposed to varying amounts of alkaloid. Further, it has been shown that *Datura* seedlings have the potential to synthesise alkaloids and to release them into the soil by foliar leaching and by exudation from the roots from as early as the sixth day of germination (James 1946, Mothes 1955). This appears to be an elegant example of a defensive adaptation whereby weed seedlings, during the period of maximum vulnerability, are protected from interference by other plants through chemicals carried in the seed coat, whilst rapidly developing their own defensive capability.

The primary mode of action of the allelochemicals of *Datura* is no less sophisticated. A recent survey (Lovett 1982b) has indicated that only about 2% of studies of allelopathy progress beyond the level of describing gross morphological

Table 3
Relative effects of *Datura* seed and seed washings on radicle growth of *Helianthus annuus*.

Treatment	Media			
	Sterile sand	Sterile loam plus sand	Black earth soil	Lateritic podzolic soil
Control (sterile water)	100	100	100	100
Seeds	68.7	76.6	84.0	57.3
Seed washings	52.2	28.2	70.5	40.3

All differences between treatment means, within media, are statistically significant.

changes. As in the case of *Camelina*, TEM has indicated disruption of normal cellular metabolism of the target plant. Specifically, the metabolism of starch by the germinating sunflower seed was adversely affected, as evidenced by the accumulation of amyloplasts in the root tips of affected seedlings (Levitt, Lovett & Garlick 1984). Significantly the allelochemicals of both *Camelina* and *Datura* disrupt metabolic processes, thus disadvantaging a competitor, rather than effecting an outright kill. Current developments in the herbicide industry have similar objectives.

The association of *Salvia reflexa* Hornem and *Triticum aestivum* L. (wheat)

Aromatic plants are valued for aesthetic and commercial reasons — aroma may also be an indicator of potential allelopathic activity (Lovett 1979). The family Lamiaceae encompasses many aromatic plants, some of which are associated with the production of essential oils for commerce and others with the production of volatile growth inhibitors. Members of the genus *Salvia* have been investigated in this latter context.

Salvia leucophylla Greene, *S. apiana* Jeps and *S. mellifera* Greene grow naturally in the soft chaparral communities of southern California and contain phytotoxic terpenes which volatilise and inhibit the establishment of seedlings of a wide variety of plants (Muller 1966). The zone of inhibition may extend 8–10 metres beyond either the lateral spread of the *Salvia* root system or the shrub crown, favouring the hypothesis that the toxic material released by these plants is volatile. Subsequent analyses revealed the presence of the monoterpenes alpha-pinene, beta-pinene, camphene, cineole and camphor, all of which inhibited the germination and radicle growth of test species. In addition, it was shown that the soil, particularly when dry, acted as a reservoir for the terpenes, accounting for long-term inhibitory effects observed in the field (Muller 1966).

Experiments with *S. reflexa* (mintweed), a weed of cropping areas in New South Wales, Queensland, South Australia and Victoria (Willis 1972) have shown that aromatic substances liberated by whole plants affect the early growth of wheat (Lovett 1982a). Wetting the foliage greatly enhances the scent of *S. reflexa* and aqueous washings of foliage have more pronounced allelopathic effects upon germination and early growth of wheat than do the aromatics alone.

Gas chromatographic analyses of foliage washings have revealed the presence of monoterpenes similar to those previously identified in *S. leucophylla*. Trichomes in the Lamiaceae are repositories for aromatics, for example, the essential oil of *Mentha piperita* L. (Clark & Menary 1980) and in *S. reflexa* it is believed that the terpenes are sequestered in trichomes pending release into the environment (Lovett & Levitt 1981). Of those identified, cineole is inhibitory to seedling growth of wheat. However, terpenes have low solubility in water and when the terpene fraction is removed from foliage washings a toxic principal, as yet unidentified, remains. The importance of water in promoting allelopathic activity is again apparent.

WIDER IMPLICATIONS OF ALLELO—CHEMICALS IN DEFENCE

The example of *Salvia* is, to date, the most significant of those cited in terms of allelopathy as a component of defence manifestations in plants. As discussed, the monoterpenes present in the genus have allelopathic effects against potential plant competitors in managed communities in Australia and in natural plant communities in California. Potts and Lovett (unpublished data) have recently identified alpha-pinene, beta-pinene, camphene and cineole, all of which are present in the Californian chaparral, from Tasmanian forest soil with which allelopathy has been associated. In Finland, Selander, Kalo, Kangas and Pertunnen (1974) carried out experiments in which the concentration of similar monoterpenes was shown to determine whether some species of insect were attracted or repelled by *Pinus sylvestris* L. (Scots pine). Franich, Gaskin, Wells and Zabkiewicz (1982) are among several groups of workers who have studied similar compounds in the context of toxicity of *P. radiata* D. Don (Monterey pine) and related coniferous species to fungi. In association with *Pseudotsuga menziesii* (Mirb.) Franco (Douglas fir) in Washington/Oregon, U.S.A., alpha-pinene has been shown to inhibit the growth of a variety of bacteria and a yeast (Andrews, Parks & Spence 1980).

Monoterpenes may also act in defence against vertebrates since Sheehy and Winward (1981), working in Oregon, found that 7 taxa of sage brush (*Artemesia* spp.) differed in their palatability to mule deer and domestic sheep. *Artemesia* spp. are high in monoterpenoids and further data showed that the concentration of alpha-pinene and an unidentified monoterpene accounted for 90% of the variation in mule deer utilization of various sage brush taxa. No doubt the increasing interest in the topic will reveal further ranges of defensive capability associated with particular chemicals.

A number of chemicals with defensive potential, including monoterpenoids, have been shown to be present in variable concentrations between

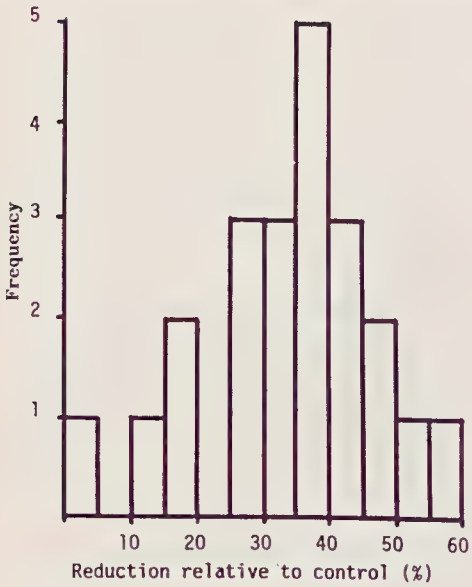

FIG. 2 — Reduction in length of first seminal root of wheat in the seedling stage by washings of *Salvia reflexa* foliage
(means of 100 seedlings for each of 22 cultivars).

and within species. They may be under simple additive or polygenic control, as in the case of alkaloids in the Solanaceae (Mann & Weybrew 1958; Levin & York 1978). Further, cultivated species subjected to chemical interference also vary in their susceptibility (fig. 2). The possibility of selection for enhanced defensive capability in both 'active' and 'passive' modes, therefore, appears to exist and such selection might be used to the advantage of agriculture, forestry and horticulture.

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(accepted Jan. 15, 1985)

RADIOCARBON DATES FOR TASMANIA, 1956–1984

by Eric A. Colhoun

COLHOUN, E.A., 1985 (31:vii): Radiocarbon dates for Tasmania, 1956–1984. *Pap. Proc. R. Soc. Tasm.* 119:39–54. ISSN 0080–4703. Department of Geography, University of Tasmania, GPO Box 252C, Hobart, 7001, Tasmania, Australia.

A list of radiocarbon dates from Tasmania and Macquarie Island is provided.

Key Words:- radiocarbon dates, Tasmania, Macquarie Island, geomorphology, palynology.

INTRODUCTION

Several hundred ^{14}C dates have been obtained from Tasmania, including Macquarie Island, during geomorphological and palynological studies of the Quaternary in the past three decades. While many dates have been published in the studies concerned others have not, and their existence is not generally known. The appended tables contain all known ^{14}C dates to December 1984, except for dates mainly of archaeological significance which have been compiled by Stockton until 1981.

The locality of the site is shown to the nearest hundred metres by providing a grid reference (GR) consisting of the number (e.g. 31) of the appropriate 1:100 000 sheet (third series) of the Department of Lands, Tasmania, together with six figures indicating eastings and northings. The abbreviation of the sheet number can be restored to the full number by inserting "7" before the first digit of the abbreviation if that digit is 6 or more, "8" if that digit is 5 or less, and by inserting the number "1" between the first and second digits of the abbreviation. Thus "31" is expanded to "8311", "94" to "7914".

All ^{14}C ages are given using the Libby half-life of 5 568 years. Isotope-enriched assays of Groningen University (GrN) are given in brackets and were made using the method of Grootes (1978). An index to laboratory codes immediately follows this introduction.

The inclusion of previously unpublished dates has been made possible by the willingness of the research workers concerned, whose names are noted in brackets in the reference column and whose addresses are listed after the tabulated section.

The purpose of listing the dates is to (1) make their existence known, and (2) to commence a ^{14}C date bank for Tasmania. To allow maintenance of the date bank workers who obtain ^{14}C dates for Tasmania are asked to forward their results to the author in the same form as produced in this listing, for computer storage until a later list is published. Some extant dates may have been inadvertently omitted from the present list. If so, details of the dates concerned would be gratefully received by the author.

LABORATORY CODES

ANU	Australian National University, Canberra, Australia
ARL	Australian Radiometric Laboratories, Sydney, Australia
Beta	Beta Analytic, Coral Gables, Florida; U.S.A.
Gak	Gakushuin University, Tokyo, Japan
GrN	University of Groningen, Netherlands
GX	Geochron Laboratories, Cambridge, Mass., U.S.A.
I	Teledyne Isotopes, Westwood, New Jersey, U.S.A.
NSW	University of New South Wales, Kensington, Australia
NZ	New Zealand, Institute of Nuclear Sciences, Lower Hutt, N.Z.
Pta	CSIR, Pretoria, South Africa
R	University of Rome, Italy
SUA	Sydney University, Australia
UB	Queens University of Belfast, Northern Ireland
V	Institute of Applied Science, Melbourne, Victoria, Australia
Y	Yale University, New Haven, Conn., U.S.A.
W	U.S. Geological Survey, Reston, Virginia, U.S.A.
WK	University of Waikato, New Zealand

TABULATION OF INFORMATION ON RADIOCARBON DATES

TASMANIA

Modern Materials

Site Name	GR Ref	Material	^{14}C	S D	Lab No	Reference	Comment
Adventure Bay	31–294985	shell of *Cellana solida*	114.6	0.9%	SUA 294/2	Gillespie 1977	nuclear test effects in southwestern Pacific
		meat of *C. solida*	117.2	1.1%	SUA 294/2M		
		shell of *Austro-cochlea odontis*	112.9	1.2%	SUA 294/3		
Eaglehawk Neck	41–759377	shell of *Brachio-dontes rostratis*	110.9	0.9%	SUA 294/1	Gillespie 1977	nuclear effects
Lake Gordon	12–tree cut by IXL, location not known	1941–45 wood of *Lagaros-trobos franklinii*					
				$\delta^{13}C$	$\Delta^{14}C$		
		benzene-ethanol extract	-24.8	*318 ± 18*	SUA 5002	Francey *et al.* 1984	pretreatment using solvent/acid/alkali/acid method
		acid extract	-20.1	*-2. ± 9*	SUA 5006		
		alkali extract	-25.1	*107 ± 37*	SUA 5007		
		wood residue	-22.9	*-16 ± 6*	SUA 5005		
		acid extract	-20.1	*21 ± 11*	SUA 5001		pretreatment using acid/alkali/acid method
		alkali extract	-25.0	*226 ± 21*	SUA 5003		
		wood residue	-22.6	*-5 ± 6*	SUA 5000		
Key Island	57–870232	shells of *Subninella undulata*	455	120	GX 7009	(Gill)	coll. 2-1-1956 at spring L.W. Pre A-bomb testing in Pacific
				$\delta^{13}C$	$\Delta^{14}C$		
Stanley River	94–565780	leaf	*-29.6*	*286 ± 9*	SUA 5008	McPhail *et al.* 1983	leaves of *Phyllocladus asplenii-folius* from below and above canopy
		leaf	*-24.0*	*293 ± 7*	SUA 5009	Francey *et al.* 1984	

Aeolian Landforms and Deposits

Site Name	GR Ref	Material	^{14}C	S D	Lab No	Reference	Comment
Bridgewater	32–167682	charcoal	4 540	105	Gak 5593	Sigleo & Colhoun 1982	midden base on dune
Glenfield	32–215696	charcoal carb. wood	210	80	SUA 303	Sigleo & Colhoun 1982	hearths in dune
		charcoal	1 245	80	SUA 304		
		charcoal	2 055	80	SUA 305		
Malcolms Hut Road	32–335643	charcoal	15 740	700	SUA 376	Colhoun 1975	Pleistocene dune
Pipe Clay Lagoon	42–433428	org. sand and clay	19 810	360	SUA 153	Colhoun 1977a	Pleistocene dune-filled wet depression
		org. sand and clay	21 905	440	SUA 153/2		
		org. clay	20 250	360	SUA 152		
		org. clay	25 380	640	SUA 151		
South Arm Beach	31–370352	charcoal	490	110	Gak 6295	(Colhoun)	midden with dune above and below
Rushy Lagoon	56–868758	charcoal	8 300	80	Beta 8190	Cosgrove 1985	hearth 0.4–0.7m depth in lunette
		wood	8 570	135	I–11 448 A	Sigleo & Colhoun 1982	organic beds below Holocene lunette
		hum. acid	8 435	185	I–11 448 B		

Cave Landforms and Deposits

Site Name	GR Ref	Material	^{14}C	S D	Lab No	Reference	Comment
Baldocks Cave	14–452966	charcoal	12 500	+3 300 -2 400	ARL 222	(Kiernan)	base of silt on gravel
Bone Cave	12–557570	charcoal	16 200	+1 200 -1 100	SUA 2104	(Goede)	archaeological site
Breccia Ridge Cave	12–554872	charcoal	7 380	130	Gak 7036	(Goede)	cave entrance deposit
		charcoal	8 290	280	Gak 7034		
Flowery Gully	25–850327	charcoal & bone	7 080	420	Gak 967	Gill 1968	bone bed in cave earth
Frankcombe Cave	12–550910	calcite	3 630	65	Pta 2505	(Goede)	stalagmite
		calcite	5 490	70	Pta 2575		
		calcite	5 790	70	Pta 2574		
		calcite	5 990	70	Pta 2571		
		calcite	6 320	70	Pta 2499		
		calcite	>41 000		SUA 2208		
Lynds Cave	14–357974	calcite	5 250	70	Pta 2979	Goede & Hitchman 1984	stalagmite
		calcite	6 400	20	Pta 3199		
		calcite	8 980	90	Pta 2976		
		calcite	10 300	90	Pta 2975		
		calcite	13 000	30	Pta 3198		
		calcite	14 200	90	Pta 3713		
		calcite	14 500	140	Pta 2972		
		calcite	13 400	130	Pta 3708		
		calcite	12 700	90	Pta 3707		

Cave Landforms and Deposits

Site Name	GR Ref	Material	^{14}C	S D	Lab No	Reference	Comment
Pigsty I Cave	14–413975	bone	23 500	+8300 –4000	ARL 223	(Kiernan)	bone in calcite on gravel
Pleisto Scene Cave	86–230748	bone	1 450	210	R 5001/1	Murray & Goede 1977	bone breccia, unreliable dates
		bone	10 100	200	R 5001/2		
		calcite	17 670	180	Pta 2506	Goede & Harmon 1983	flowstone over bone breccia
Quarry Cave	14–454980	charcoal	1 810	310	ARL 221	(Kiernan)	clay below calcite crust
Titans Shelter	12–557852	charcoal	1 140	90	Gak 6874	Goede & Murray 1979	cave deposits
		charcoal	14 310	+2970 -2160	Gak 6875		cave bone deposit

Coastal Landforms and Marine Sediments

Site Name	GR Ref	Material	^{14}C	S D	Lab No	Reference	Comment
Anthonys Beach	96–471805	shell hash	3 500	60	SUA 1301	Thom *et al.* 1981	barrier transect
		shell hash	1 780	55	SUA 1302		
		shell hash	7 660	75	SUA 1303		
Bowen Bridge	32–250593	org. mud	790	70	SUA 1960	Colhoun & Moon 1984	– 10.5m drill hole 2, piers 2 & 3
		shell	1 490	70	SUA 1961		– 16.1m
		org. mud	3 080	80	SUA 1962		– 19.0m
		shell	2 060	150	SUA 1963		– 26.3m
		shell	4 440	150	SUA 1964		– 29.5m
		org. mud	7 370	140	SUA 1965		– 29.5m
		org. mud	4 490	90	SUA 1966		– 30.0m
		org. mud	9 070	110	SUA 1967		– 35.5m
		shell	9 150	290	SUA 1968		– 38.9m
		shell	9 060	300	SUA 1969		– 40.0m
		org. mud	9 390	110	SUA 1970		– 42.5m
		shell	2 610	100	SUA 1971		– 24.0m pier 6
		shell	2 560	160	SUA 1972		– 32.4m pier 4
		shell	3 190	180	SUA 1973		– 10.3 to – 10.5m drill hole 10
		shell	7 960	320	SUA 1974		– 42.9 to – 43.2m drill hole 2
Cremorne	42–429439	carb. wood	3 620	80	Gak 650	Kigoshi & Kobayashi 1966	beach sands 1.3m above HWMST
Greens Beach	25–787515	shell hash	6 085	90	SUA 1297	Thom *et al.* 1981	barrier transect
		shell hash	38 765	+2700 -2015	SUA 1298		
		shell hash	8 005	90	SUA 1299		
		shell hash	3 770	70	SUA 1300		
Laycocks Beach	15–455429	charcoal & carb. wood	5 990	260	Gak 5618	Colhoun 1983a	present sea level already attained
Marion Bay	42–710572	carb. wood	390	90	Gak 647	Kigoshi & Kobayashi 1966	sample 0.2m asl in barrier beach
Nelsons Drain, Flinders Island	57–010...	shell	21 620	750	Gak 8256	(Ladd)	shell from drain wall

Coastal Landforms and Marine Sediments

Site Name	GR Ref	Material	^{14}C	S D	Lab No	Reference	Comment
Nilinga Creek, Flinders Island	57–865565	shell	3 990	100	SUA 413	(Gill)	beach gravel + 1.8m
Nine Mile Beach	53–905395	shell hash	5 760	80	SUA 1291	Thom *et al.* 1981	barrier transect
		shell hash	9 465	105	SUA 1292		
		shell hash	11 350	125	SUA 1293		
		shell hash	8 770	120	SUA 1294		
		shell hash	11 110	175	SUA 1295		
		shell hash	8 575	105	SUA 1296		
Rheban	42–777777	shell hash	3 445	140	GX 4021	Thom *et al.* 1981	barrier transect
		shell hash	3 550	150	GX 4020		
		shell hash	4 330	125	SUA 768/1		
		wood	815	125	SUA 768/2		
		shell hash	4 750	180	GX 4363		
		shell hash	5 310	150	GX 4022		
		shell hash	4 330	170	GX 4364		
		shell hash	4 340	120	GX 4365		
Rocky Cape	06–743753	shell	<190	—	unknown	(Stephens)	beach 1.8m above HWMST east side of Rocky Cape
	06–.....	shell	3 795	100	V 83		probably west side of Rocky Cape
	06–.....	shell	3 434	95	V 88		
Seven Mile Beach	42–470581	shell	4 140	90	SUA 1486	Thom *et al.* 1981	near base of deposit below swale south of inner beach ridge
Snug	31–211321	shell	510	80	Gak 1143	Kigoshi & Kobayashi 1966	sand 0.7m below HWMST
		shell	2 760	120	Gak 649		sand 1.7m below HWMST
The Jam, Smithton	96–353830	shell	22 700	1100	Gak 652	Kigoshi & Kobayashi 1966	derived Pleistocene shell at -3m
Tinderbox	31–270325	shell	260	70	Gak 648	Kigoshi & Kobayashi 1966	beach 0.5 – 2m above HWMST
Yellow Beaches, Flinders Island	57–064479	wood	3 970	90	Gak 1102	(Gill)	at Lady Barron below Henwoods House

Fluvial Landforms and Deposits

Site Name	GR Ref	Material	^{14}C	S D	Lab No	Reference	Comment
Barilla Valley	32–378583	charcoal	550	80	Gak ?	(Stephens)	alluvial gravel
	32–353572	charcoal	1 160	100	Gak 651	Kigoshi & Kobayashi 1966	alluvial gravel
	32–343564	charcoal	4 650	120	Gak 488		alluvial gravel
		charcoal	7 900	460	Gak 487		alluvial gravel
Blakes Opening	21–690279	charcoal	>29 150		Gak 5587	Colhoun & Goede 1979	alluvium containing organic beds
		charcoal	27 400	2900	Gak 5588		
		charcoal	29 340	+3080 -2220	Gak 5589		
		charcoal	39 600	1000	GrN 7695		

Fluvial Landforms and Deposits

Site Name	GR Ref	Material	^{14}C	S D	Lab No	Reference	Comment
		wood	41 150	+1450 -1250	GrN 7999		
		wood	53 400	+1700 -1400	GrN 8277		
City of Melbourne Bay, King Island	77–535671	wood	37 500	1900	NZ 349	Grant-Taylor & Rafter 1962	*Nothofagus* in alluvium below dune
Coal River	32–371763	charcoal	1 730	110	Gak 1678	Kigoshi *et al.* 1969	alluvium
	32–364668	charcoal	1 990	100	Gak 905		alluvial silty sand
	32–359693	soil carbonate	2 240	110	Gak 2236		pedal coating of alluvium
	32–370662	charcoal	5 480	130	Gak 2238		alluvial sand
	32–363668	charcoal	33 600	+3400 -2400	Gak 906		alluvial gravel reworked
Curries River	25–960501	charcoal	370	100	SUA 1081	(Colhoun & van de Geer)	Holocene & Pleistocene alluvial deposits
		wood	1 460	80	SUA 1082		
		wood	1 280	100	SUA 1043		
		wood	12 570	240	SUA 1083		
Denison River	02–048699	charcoal	310	150	ANU 2787	(Jones & Ranson)	alluvial silt 0.05m below rainforest peat
		plant fragments	13 110	400	SUA 1084		
Narcissus River	13–256484	charcoal	7 650	250	SUA 2079	(Kiernan)	basal 0.2m of alluvium on outwash gravel
Native Hut Rivulet	32–352769	charcoal	4 160	160	Gak 2237	(Goede)	alluvium
Oyster Creek	32–118651	charcoal	3 840	95	I 7931	Wasson 1977	inset fill of alluvial fan
Parramore Creek	32–148671	charcoal	3 575	95	I 7930	Wasson 1977	inset fill of alluvial fan
Pieman Dam	94–472742	wood	>39000		SUA 310	Colhoun 1980	interglacial age alluvium
		wood	>54000		GrN 7555		same piece wood as SUA 310
Rocky Cape	96–726741	charred wood	26 760	1360	Gak 5153	Colhoun 1977b	organic materials in alluvial fan deposits
		wood	28 930	+1970 -1580	Gak 5154		
		charcoal & carb. wood	33 240	+5610 -3270	Gak 5691		
		wood	24 090	1030	Gak 5155		
		charcoal & carb. wood	32 350	+3680 -2510	Gak 5690		
Stanley River	94–565780	wood	100	60	SUA 5015	Francey *et al.* 1984	logs of *Lagarostrobos franklinii* from alluvium listed chronologically
		wood	120	60	SUA 5016		
		wood	630	60	SUA 5021		
		wood	1 190	70	SUA 5014		
		wood	1 210	70	SUA 5013		
		wood	1 580	60	SUA 5011		

Fluvial Landforms and Deposits

Site Name	GR Ref	Material	^{14}C	S D	Lab No	Reference	Comment
		wood	1 980	60	SUA 5012		
		wood	2 050	50	SUA 5010		
		wood	3 680	40	SUA 5023		
		wood	3 750	40	SUA 5025		
		wood	4 090	40	SUA 5027		
		wood	4 670	70	SUA 5019		
		wood	5 500	50	SUA 5020		
		wood	6 190	60	SUA 5004		
		wood	4 080	70	SUA 5018		logs of *Phyllocladus aspleniifolius*
		wood	4 410	50	SUA 5026		
		wood	12 390	80	SUA 5022		outer wood of SUA5028
		wood	12 870	90	SUA 5028		inner wood of SUA5022
Tea Tree Rivulet	42–639798	charcoal	3 040	90	Gak 1677	Kigoshi *et al.* 1969, Goede 1973	alluvium
		charcoal	3 850	90	Gak 1148		alluvium
		wood	4 360	90	Gak 1147		alluvium
		wood	4 435	110	GX 99		alluvium
		charcoal	5 720	120	Gak 1289		alluvium
		wood	6 200	200	Gak 1146		same horizon as preceding date

Glacial Landforms and Deposits

Site Name	GR Ref	Material	^{14}C	S D	Lab No	Reference	Comment
Conglomerate Creek	03–815406	wood	30 050	2000	ANU 2535	(Colhoun)	min. age of organic bed between tills
Crooked Lake	12–410893	detritus mud	5 970	100	SUA 1355	(Colhoun and Macphail)	min. age of mud in channel outside lateral moraine
Dante Site on King River	03–902459	wood	18 800	500	ANU 2533	(Kiernan & Colhoun)	twigs in base of outwash silt and sand
		Donatia novae zelandiae	21 180	370	SUA 2154		cushion in alpine humus soil
		wood	20 100	470	SUA 2155		twigs in silt below soil
Fish River Road	14–373746	charcoal	>28000		SUA 1938	(Hannan & Colhoun)	charcoal in lateral moraine
Gormanston	03–834410	wood	1 560	250	ANU 2534	(Kiernan & Colhoun)	wood intrusive in varved clays
Lake Nancy	03–032207	wood & leaf fragments	8 720	220	Gak 671	Peterson 1968	min. age deglaciation
Linda Creek	03–835422	wood	26 480	800	W 323	Gill 1956	wood in varved clays
		wood	>40000	NZ 348	Grant-Taylor & Rafter 1962, 1963	clayey sands of preglacial age	
		wood	27 800	700	ANU 2480A	Colhoun 1985	wood in glacial sands
		α cellulose	23 100	600	ANU 2480B		same wood as ANU 2480A
Mackintosh Dam	04–872825	charcoal	>35000		SUA 1289	Colhoun 1985	till >^{14}C limit

Lake, Swamp and Peat Deposits

Site Name	GR Ref	Material	^{14}C	S D	Lab No	Reference	Comment
Adamsons Peak	21–867004	carbon fragments	9 080	200	I 7571	Macphail & Peterson 1975	2.5m in core in cirque
Badger Beach	25–740507	wood	7 380	100	NZ 1219	Fish & Yaxley 1966	tree stump in intertidal peat bed
		peat	8 020	140	Gak 5622	(Chick)	peat bed at high tide
		peat	7 850	140	Gak 5621		peat bed at mid tide
		peat	31 960	+3400 -2380	Gak 5620		wave-worn peat masses derived from below low tide
Beatties Tarn	22–705752	*Eucalyptus* leaves	9 050	200	Gak 878	Macphail 1979	1.4m in core in cirque lake
		lake mud	7 850	150	SUA 324		1.4–1.65m
		lake mud	11 420	205	SUA 325		3.2–3.4m
Ben Lomond, Rodway Valley	44–557991	wood fragments	3 080	90	Gak 670	Caine 1983	peat over blockstream; formerly Talus Valley
Bird River Track	03–837110	wood	1 290	70	SUA 5017	Francey *et al.* 1984	log of *Lagarostrobos franklinii*
Borradaile Plains	14–318857	peat	10 480	180	Gak 785	(Peterson)	peat from depression in glacial drift
Broad Valley	22–661791	sedges	3 050	104	NSW 29B	Caine 1968	1m depth
	22–659797	sedges	3 500	80	NSW 37B		1.25m depth
Broadmeadows Swamp	36–385733	peat	11 410	770	Gak 5969	(van de Geer *et al.*)	Holocene & late Pleistocene swamp deposits at 0.70, 0.85 & 1.0m
		peat	15 100	750	Gak 7556		
		peat	27 600	+1700 -1430	Gak 6324		
Brown Marsh	23–643305	peat	3 490	90	ANU 2744	Macphail & Hope 1985	2.7m depth in core 2
		peat	8 575	125	I 9558	Macphail 1979	3.1m
		peat	4 930	180	Gak 984	(Peterson)	5.1m depth in core 1
Camerons Lagoon	24–732545	algal gyttja	2 670	70	ANU 3974	(Thomas)	0.2–0.28m in core
			7 500	130	ANU 3976		0.32–0.37m
			7 750	150	ANU 2739		0.52–0.59m
Darwin Crater	03–892153	peat	>51 000		GrN 7694	(Colhoun & van de Geer)	6.32–6.38m in 1972 core
Dublin Bog	14–371815	org. mud	8 920	140	SUA 2191	(Colhoun & Hannan)	4.16–4.21m in core
		org. mud	11 710	190	SUA 2190		6.24–6.29m
		org. mud	13 150	240	SUA 2189		7.34–7.46m
		charcoal in lake clay	13 400	600	SUA 2188		8.30–8.46m
Dyes Marsh	13–485385	peat	4 930	180	Gak 784	(Derbyshire)	5.2m depth
Eagle Tarn	22–664745	org. mud	9 960	300	SUA 323	Macphail 1979	3.9–4.1m
		org. mud	11 400	240	I 7685		4.4–4.6m
		org. mud	6 300	400	ANU 3106	(Green)	2.1–2.2m in core
		org. mud	6 420	380	ANU 3108		2.5–2.6m
		org. mud	7 440	500	ANU 3112		3.3–3.4m
		org. mud	7 460	350	ANU 3113		3.5–3.6m

Lake, Swamp and Peat Deposits

Site Name	GR Ref	Material	^{14}C	S D	Lab No	Reference	Comment
		org. mud	9 650	850	ANU 3114		3.7–3.8m
		org. mud	8.300	490	ANU 3115		3.9–4.0m
		org. mud	6 340	190	ANU 3116		4.1–4.2m
		org. mud	7 460	380	ANU 3117		4.3–4.4m
		org. mud	12 960	950	ANU 3118		4.5–4.6m
Gordon Road	12–510657	wood	33 240	+3370 -2370	Gak 5625	(Colhoun)	base of ice-pushed organic clays. Probably a minimum age.
Hartz Lake	21–805128	peat	2 930	100	SUA 1357	(Colhoun & Macphail)	0.5–0.59m
		lake clay	4 100	200	SUA 1944		0.71–0.9m in lake clay of core
		lake clay	Modern		SUA 1945		1.6–1.89m
Henty Bridge	94–734495	org. clay	23 640	1030	Gak 5597	Colhoun 1979	lake clays and slope deposits on till
		org. clay	25 660	1200	Gak 5596		
		wood	>34 600		Gak 5595		
		wood	>34 190		Gak 6294		
		wood	23 860	890	Gak 5594		
Henty Surface Swamp	04–786537	org. mud	>4 380		Gak 6292	(Colhoun)	1.98–2.0m in core
Hogsback	21–874945	wood	750	60	SUA 2110	(Podger)	*Telopea* rootstock at 0.5m depth in peat
Hogsback Plain	21–863960	charcoal	11 600	100	SUA 2109	(Podger)	base peat at 1.2m
Homestead Swamp Hunter Island	86–094110	peat	4 100	80	ANU 2532	(Hope)	sandsheet stabilised
James Tarn, Mount Field	22–641757	org. mud	8 280	460	Gak 1158	Macphail & Peterson 1975	1.5m in core
Killiecrankie Bay, Flinders Island	48–719900	sandy peat	12 550	390	Gak 8261	(Ladd)	2.45m in core
		peat	>33 890		Gak 8923		3.2m
		peat	29 630	3030	Gak 8922		4.25–4.28m
Killiecrankie Swamp, Flinders Island	48–715898	wood	550	140	Gak 8263	Ladd 1981	2.0m depth
Lagoon of Islands	23–940390	peat	7 430	150	unknown	(Jackson)	base peat
Lake Tiberias	33–300020	peat	9 550	200	Gak 2239	Macphail & Jackson 1978	base of organic deposit ~ 2m depth
Lake Vera	03–078193	org. clay	6 950	175	I 9557	Macphail 1979	2.08–2.13m in core
		org. clay	11 530	240	I 7683		2.7–2.8m
Lake Wurawina, Upper Cirque	12–405900	peat	10 360	170	SUA 1354	(Colhoun & Macphail)	1.65–1.75m in core
Laughing Jack Lagoon	13–415320	wood	810	60	SUA 1957	(Kiernan)	0.45–0.5m
		wood	1 540	60	SUA 1958		~ 1m depth in silt
Lower Mackintosh Valley	04–869822	wood	36 200	+3400 -2400	SUA 1287	(Colhoun & Sansom)	0.9m in section
		charcoal	>31 700		SUA 1288		1.7–1.75m in section
Mickelthwaite Marsh	05–846106	peat	7 030	110	I 11863	(Colhoun & van de Geer)	0.85–0.9m in core
Middle Patriarch Swamp, Flinders Island	58–009719	peat	940	110	Gak 8921	(Ladd)	0.65–0.7m in core

Lake, Swamp and Peat Deposits

Site Name	GR Ref	Material	^{14}C	S D	Lab No	Reference	Comment
		peat	5 920	150	Gak 8920		1.4–1.45m
		peat	10 110	420	Gak 8258		1.7–1.75m
Mount Gould Plateau	14–220512	org. silt	7 920	250	SUA 2080	(Kiernan)	1.6m in core
Mount McCall	03–956100	wood	2 740	60	SUA 2108	(Podger)	*Athrotaxis* wood partly buried
Mount Strzelecki, near summit	57–914496	peat	1 510	130	Gak 8260	(Ladd)	0.84–0.86m on rock
Mowbray Swamp	96–365760	marl	>37760		Y 148/1	Barendsen *et al.* 1957	0.6m depth in swamp
		peat	>37760		Y 148/2		0.6–1.2m
		tree stump	47 500	+2700 -2000	GrN 7481	(van de Geer *et al.*)	1.35m in spring mound
		root stump	36 300	700	GrN 8606		0.85m depth in pit
		humic extract	34 100	700	GrN 8646		of GrN 8606
		peat	46 400	+1300 -1100	GrN 9341		1.075–1.125m
		humic extract	45 200	+2600 -2000	GrN 9765		of GrN 9341
		root stump	>52000		GrN 9342		1.2–1.3m
		root stump	(52 220	350)	GrN 9742		Same sample as GrN 9342
		humic extract	(51 300	+4400) -2800)	GrN 9767		of GrN 9742
Ooze Lake	20–758837	lake clay	5 440	90	SUA 1939	(Colhoun & Macphail)	1.0–1.2m in core
		lake clay	8 870	130	SUA 1940		2.0–2.2m
		lake clay	10 390	160	SUA 1941		3.0–.3.2m
		lake clay	10 670	170	SUA 1942	Macphail & Colhoun 1985	4.0–4.2m
		lake clay	12 100	160	SUA 1356		4.77–5.07m
		lake clay	12 590	230	SUA 1943		5.5–5.7m
		lake clay	17 700	400	SUA 1359		6.4–6.65m
Phillips Creek	45–512058	wood	8 475	85	Beta 1885	Caine 1983	0.8m depth in core 2
		lake clay	9 535	165	Beta 1886		2.25m
		clay with charcoal	6 270	760	ANU 2512	(Noble)	2.27m core 1
Poets Hill Lake, formerly referred to as Inter-moraine Lake	04–807508	org. mud	3 600	180	SUA 1394	Colhoun 1979	0.505–0.54m core 2
		org. mud	10 150	220	SUA 1395		1.82–1.86m core 2
		org. mud	7 410	400	SUA 1396		2.85–2.9m core 2 believed unreliable
		org. mud	11 420	770	Gak 6297		2.9–2.95m core 1
Pulbeena Swamp	96–436724	peat	13 690	550	Y 229/1	Barendsen *et al.* 1957	0.62–0.8m depth in swamp
		shell marl	27 900	2000	Y 229/2		1.70m
		wood	54 200	+11000 -4500	GrN 7322	Banks *et al.* 1976	2.3m in profile of 1975
		humified peat	11 370	70	GrN 7881	Colhoun *et al.* 1982	0.6m depth in section of 1976
		humified peat	14 980	80	GrN 7688		0.75m

Lake, Swamp and Peat Deposits

Site Name	GR Ref	Material	^{14}C	S D	Lab No	Reference	Comment
		humified peat	16 590	110	GrN 7882		0.85m
		humified peat	22 130	180	GrN 7689		1.15m
		charred root stump	44 700	1500	GrN 7690		1.65m
		charred root stump	42 200	800	GrN 9458		1.65m
		root stump	48 400	+1900 -1600	GrN 7691		2.0m
		root stump	53 400	+3700 -2500	GrN 9459		2.0m
		root stump	(42 700	900)	GrN 8589		2.05–2.15m
		humic extract	(41 100	800)	GrN 8636		of GrN 8589
		root stump	41 450	700	GrN 9438		
			(42 620	200)	GrN 9483		same sample as GrN 9438
		root stump	(48 200	250)	GrN 8526		2.55–2.65m
		humic extract	(47 500	800)	GrN 8626		of GrN 8526
		root stump	(49 250	300)	GrN 8754		3.2–3.3m
		humic extract	(47 600	+1900) (-1500)	GrN 8627		of GrN 8754
		peat in shell-marl	>55000		GrN 9798		4.2–4.25m
		peat in shell-marl	(55 200	500)	GrN 9905		same sample as GrN 9798
		shell-marl	42 500	1100	GrN 9844		same horizon as GrN 9789
Sundown Point	85–044445	peat	420	60	ANU 2531	(Hope & Ranson)	0.21–0.27m
		peat & org. mud	3 300	80	ANU 2530		0.8–0.9m, stabilisation coastal dune
Scotts Peak Dam	11–445235	carb. wood	>33600		Gak 5624	(Colhoun)	wood in ice-pushed? lake clays
Tarraleah	13–557162	peat	7 000	160	ANU 2496	Macphail 1984	0.4–0.5m depth in core
		peat	7 970	180	ANU 2745		1.1–1.2m
		org. clay	9 080	195	I 9559		2.5–2.54m
Tullabardine Creek	96–879843	peat	8 030	110	SUA 2185	(Colhoun & van de Geer)	1.2m depth in monolith
		peat	11 060	210	SUA 2186		1.35m
		wood	11 660	150	SUA 1044		1.6m in section
		org. soil	21 250	270	SUA 1045		1.9–2.1m
		wood	31 500	900	SUA 1046		3.05–3.1m in monolith
		wood	>43800		SUA 1047		3.8m
Tyndall Plateau	96–824545	org. clay	9 050	120	SUA 1358	(Colhoun & Macphail)	0.82–0.94m in core

Lake, Swamp and Peat Deposits

Site Name	GR Ref	Material	^{14}C	S D	Lab No	Reference	Comment
Unnamed Tarn, Mount Field	22–640758	org. mud	3 570	115	I 750	(Peterson)	0.35–0.4m
		org. mud	9 590	240	I 8007	Macphail & Peterson 1975	1.5m in core
		org. mud	9 725	180	I 8008		3.0m

Slope Deposits

Site Name	GR Ref	Material	^{14}C	S D	Lab No	Reference	Comment
Barilla Hills	32–343564	charcoal	6 490	100	UB 919	(Stephens)	silt with charcoal below mudstone slope deposits
Ben Lomond, Pig Run Creek	44–500037	charcoal	3 940	110	Beat 2109	Caine 1983	
Chester Rivulet	04–784795	charcoal	18 190	340	SUA 1042	(Colhoun)	in soil at 5.7m depth in scree
Gellibrand Point	32–332428	carb. wood	>37000		SUA 309	Colhoun 1975	strongly weathered chemically
Hardstaff Creek	15–195367	charcoal	13 870	820	Gak 5968	(Colhoun)	1.9m depth in scree
Mathinna Plains	45–712145	charcoal	2 340	90	Gak 669	Caine 1978	at 2m depth in scree
Remarkable Cave	41–686178	wood	40 000		SUA 347	Colhoun 1977c	in 17m of slope deposits
		wood & plant detritus	>40000		SUA 348		
		wood	>40000		SUA 349		
		peaty clay	>37000		SUA 389		
		charcoal & wood	>37000		SUA 391		
		charcoal	29 050	830	SUA 154		contaminated by humic acid
Rokeby	32–389493	wood	470	90	Gak ?	(Stephens & van de Geer)	slope deposits on cliff
Sayers Hill	15–365378	charcoal	>30600		Gak 5590	Colhoun 1976	at 5m depth in slope deposit

Soils and Palaeosols

Site Name	GR Ref	Material	^{14}C	S D	Lab No	Reference	Comment
Badger Beach	25–694471	org. clay	15 900	510	Gak 5619	(Chick)	Podzol below dune and on beach sands
Ben Lomond, Land of Little Sticks	44–537029	peaty soil with charcoal	4 940	90	ANU 2513	Caine 1983	0.76–0.77m depth
Ossians Throne	44–580992	org. soil	1 250	70	Beta 2110	Caine 1983	buried A horizon
Ben Lomond, Road	44–518050	org. soil	19 410	330	Beta 1887	Caine 1983	covered by blocky mantle
Fern Tree	32–204471	charcoal	>40000		I 8155	Colhoun 1975	buried Bt horizon
Florentine Valley	12–553815	charcoal	14 200	700	Gak 486	Davies 1974	Podzol A horizon below solifluction
Linda Creek	03–835422	wood	>40000		R 488	(Banks)	*Phyllocladus* stump below glacial sands
		wood	>48500		ANU 3413	(Colhoun & Kiernan)	*Phyllocladus* stump below glacial sands

Soils and Palaeosols

Site Name	GR Ref	Material	^{14}C	S D	Lab No	Reference	Comment
Monpeelyata Canal	23–730385	plant detritus	2 900	80	Gak 1020	(Derbyshire)	*Astelia alpina* below solfluction but on same level as Gak 1163, date suspect
		charcoal	30 400	2300	Gak 1163	Derbyshire 1968	soil below solifluction deposit
Mount Albert	45–742200	wood & charcoal	3 520	100	Gak 668	Caine 1978	buried Podzolic A horizon
Mount Arrowsmith	13–255261	charcoal	13 000	640	SUA 1959	(Kiernan)	palaeosol below 1m scree
Scotts Peak Dam	11–421351	wood	>33000		Gak 5623	Colhoun 1975	organic soil within scree
Welcome River	86–111863	charcoal	30 860	+4100 -2770	Gak 5970	Colhoun 1983b	palaeosol below Holocene beach & dune

MACQUARIE ISLAND

Site Name	Lat	Long	Material	^{14}C	S D	Lab No	Reference	Comment
Bauer Bay	50 30	158 53	peat	2 165	80	SUA 179	Colhoun & Goede 1973	min. age 9m beach
			king penguin bones	3 980	140	Gak 644	McEvey & Vestjens 1974	7m depth
Finch Creek	54 35	158 55	royal penguin bones	6 100	120	Gak 643	McEvey & Vestjens 1974	in 6m terrace near river mouth
Finch Creek, Ridge	54 34	158 55	peat	3 780	140	SUA 1460	Selkirk & Selkirk 1983	1.27m depth
			sandy peat	10 275	230	Beta 1386		1.82m
			sandy peat	5 930	240	SUA 1845X	Selkirk *et al.* 1984	1.9m
			sandy peat	5 260	85	Beta 7027	(Selkirk & Selkirk)	1.9–2.0m
			humic acid	5 430	80	Beta 7027B		of Beta 7027
			sandy peat	5 630	80	SUA 2126		1.9–2.0m
Gentoo Flat	54 32	158 53	peat	modern		Beta 6735	(Dodson)	0.05m
			peat	modern		Beta 6736		0.05–0.10m
			peat	modern		Beta 6737		0.25–0.28m
Green Gorge	54 38	158 54	peat	2 074	80	SUA 178	Colhoun & Goede 1973	min. age 9m beach
Green Gorge Lake	54 38	158 54	peat	1 570	140	SUA 1463	Selkirk & Selkirk 1983	1.2–1.4m depth
			peat	7 630	280	SUA 1465		2.2–2.3m
Green Gorge Ridge	54 38	158 54	peat	5 140	140	SUA 1462	Selkirk *et al.* 1984	0.88m depth
			peat	6 900	+900 -800	SUA 1461	Selkirk & Selkirk 1983	1.38m
			peat	7 200	130	SUA 2164	Selkirk *et al.* 1984	repeat SUA 1461 from adjacent profile
Perseverance Bluff	54 30	158 56	peat	220	55	Beta 8080	(Dodson)	0.15–0.2m
			peat	<75		Beta 8081		0.2–0.25m
			peat	300	55	Beta 8082		0.25–0.3m
			peat	385	60	Beta 8083		0.3–0.35m
			peat	625	60	Beta 8084		0.35–0.4m
			peat	1 245	80	Beta 8085		0.4–0.45m
			peat	1 685	70	Beta 8086		0.5–0.58m

MACQUARIE ISLAND

Site Name	Lat Long	Material	^{14}C	S D	Lab No	Reference	Comment
Scoble Lake	54 31 158 56	org. mud	3 140	100	Wk 407	Salas 1983	0.78m depth at core base near eastern edge of lake
		org. mud	7 160	260	Wk 405		top of core from centre of lake
		org. mud	8 700	220	Wk 349		base core at 2m depth
The Nuggets	54 32 158 57	peat	1 700	110	SUA 1468	Selkirk & Selkirk 1982	0.47–0.5m in cliff section
		org. clay	8 560	200	SUA 1467		1.47–1.5m
		diatomite	8 230	240	SUA 1466		3.39–3.41m
		lake clay	9 400	220	SUA 1894	Selkirk *et al.* 1984	4.4m
Wireless Hill	54 30 158 57	sandy peat	760	100	SUA 1681	Selkirk *et al.* 1983	1.0–1.05m depth
		peat	1 515	75	SUA 1238	Selkirk & Selkirk 1983	1.25–1.35m
		sandy peat	1 600	130	SUA 1459	Selkirk *et al.* 1983	2.06–2.1m
		humic acid	1 300	90	SUA 1459HA		of SUA 1459
		sandy peat	3 490	210	SUA 1682		3.13–3.15m
		sandy peat	5 140	140	Beta 1387		3.58–3.60m
		sandy peat	4 880	90	SUA 1527		3.84–3.94m
		humic acid	4 610	100	SUA 1527HA		of SUA 1527

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A NEW SPECIES OF *GALAXIAS* (PISCES : GALAXIIDAE) FROM SOUTHERN TASMANIA

by A.P. Andrews

(with 3 tables, one text-figure and one plate)

ANDREWS, A.P., 1985 (31:vii): A new species of *Galaxias* (Pisces : Galaxiidae) from southern Tasmania. *Pap. Proc. R. Soc. Tasm.* 119:55–60, one pl. ISSN 0080–4703. Tasmanian Museum & Art Gallery, Hobart, Tasmania, Australia, 7000.

A new species of *Galaxias* from southern Tasmania is described and figured. The probable mode of origin and relationship with other members of the genus are discussed.

Key Words: *Galaxiidae*, Tasmania

INTRODUCTION

Since the revision of the family in Tasmania by Andrews (1976), further systematic collecting in various parts of the State has revealed two additional species of *Galaxias* and three species of *Paragalaxias* (see McDowall & Frankenberg, 1981). The finding of another new species of *Galaxias* in the Mount La Perouse area is not altogether surprising as there appears to have been little, if any, systematic collecting carried out in the area previously.

The Tasmanian members of the genus *Galaxias* fall naturally into two groups: the broad-ranging diadromous species *G. maculatus* (Jenyns), *G. truttaceus* Valenciennes and *G. brevipinnis* Gunther; and the lacustrine species which are usually greatly restricted in distribution. Two of the lacustrine species, *G. johnstoni* Scott and *G. pedderensis* Frankenberg, were considered by Frankenberg (1969) to be closely related to *G. olidus* Gunther from the Australian mainland. Later Fulton (1978) described another related species, *G. fontanus*, from the Swan River and all four were treated as related species by McDowall and Frankenberg (1981).

As the species described here also appears to be morphologically most closely related to this group, meristic and morphometric data are provided for all four Tasmanian species by way of comparison.

FIG. 1 — Map of Tasmania showing the distributions of *Galaxias niger* n.sp. and *G. fontanus*, *G. johnstoni* and *G. pedderensis*. *G. pedderensis* —solid circle; *G. johnstoni* — solid triangle; *G. fontanus* — circle with star; *G. niger* n.sp. — solid star.

MATERIALS AND METHODS

A sample of thirty specimens was collected by the writer (21.III.1984) from the Reservoir Lakes (map reference DM 780 850, Tasmania 1:100 000 topographic survey, sheet 8211, edition 1) in the Mount La Perouse area. The sample was obtained by the use of a fish trap (Andrews, 1976) and the specimens relaxed using quinaldine, fixed in 10% formaldehyde and later transferred to 70% ethanol. Three of the specimens were cleared and stained for osteological study.

Measurements and counts are generally those of Hubbs and Lagler (1958) but following McDowall (1972) all segmented fin rays, branched and unbranched, were counted in the dorsal and anal fins, a procedure not followed by Andrews (1976), and vertebral counts exclude the hypural centra. Meristic and morphometric data are based on a series of twenty specimens which ranged in standard length from 63 mm to 105 mm.

Type material has been deposited in the Tasmanian Museum and Art Gallery, Hobart; Queen Victoria Museum and Art Gallery, Launceston; and the Australian Museum, Sydney.

Abbreviations used in the text are as follows: LS standard length (snout tip to hypural joint), HL head length (snout tip to posterior edge of opercular flap), S-DO snout tip to dorsal fin origin, S-VO snout tip to ventral fin origin, PL pectoral fin length, PB-VO pectoral base to ventral fin origin, VL ventral fin length, VB-AO ventral base to anal origin, DCP minimum depth of caudal peduncle, LCP dorsal length of caudal peduncle, ED eye diameter, UJL upper jaw length, LJL lower jaw length, GW gape width, IW interorbital width, HW head width, AMS Australian Museum Sydney, QVML Queen Victoria Museum and Art Gallery Launceston, TMH Tasmanian Museum and Art Gallery Hobart.

SYSTEMATIC ACCOUNT

Galaxias niger n.sp.

Diagnosis

Galaxias niger n.sp. differs from *G. johnstoni, G. pedderensis* and *G. fontanus* by the more numerous pectoral fin rays and vertebrae, the wider head and gape and the heavier pigmentation. It differs from *G. olidus* by the very much wider head and gape, the longer and narrower caudal peduncle, heavier pigmentation and the regular possession of two pyloric caeca. *G. niger* also differs from *G. fontanus* by the absence of enlarged lateral canine teeth and the presence of only four laterosensory pores in the row below the eyes.

Etymology

Niger, from the Latin meaning black, is a reference to the heavy pigmentation.

Types

The species is known from the holotype, TMH No. D1926 (96.0mmLS) and six paratypes that have been distributed as follows: TMH No. D1927, D1928 (101.0mmLS, 106.0mmLS); QVML No. 1984/5/12, 1984/5/13 (91.4mmLS, 80.4mmLS); AMS No. I2488.001 (94.0mmLS, 90.0mmLS). All types were collected 21.III.1984 by the writer from the Reservoir Lakes, southern Tasmania.

Description

A medium sized species (*sensu* McDowall & Frankenberg, 1981), body stout and markedly flattened anteriorly, paired and vertical fins small, pectorals almost circular (plate 1). Anal fin inserted beneath the first third of dorsal base, caudal fin only slightly emarginate. Head large and wide, flat to slightly concave between the orbits. Snout blunt and rounded, jaws very long, lower conspicuously shorter than the upper, angle of jaws extending posteriorly to beneath middle of eye. Two well-developed pyloric caeca present, length equal to about twice the diameter. Canine teeth absent.

Colour

In life, colour is a uniform deep olive brown with numerous large irregular dark brown blocks and bars on the sides, extending well down the sides towards the abdominal surface. All fins a dark translucent brown with conspicuously pigmented rays. A row of about twelve roughly circular brown spots extending from the snout tip along the dorsal midline to the origin of the dorsal fin. A conspicuous dark post-pectoral vertical bar present and usually two, sometimes one, vertical bars on the caudal fin near the base. On preservation the background colour appears as a uniform dark grey and the brown patches a dense black.

Osteology

Eight or nine branchiostegal rays, gill rakers thin and widely spaced, about ten on each lower side of the anterior arch. All jaw teeth very small, no enlarged lateral canines, a single row of about eight teeth on the inner borders of each mesopterygoid, lingual teeth large. Prepelvic parapophyses not fused to the centra, epipleural ribs present.

Meristic and Morphometric Variation

The data presented in tables 1–3 are based on a series of twenty specimens. Comparative data on *G. johnstoni, G. pedderensis* and *G. fontanus* are based on the following series; *G. johnstoni* TMH D1116, Clarence Lagoon, Tasmania, 4.IV.1971, (1); TMH D1742, Clarence Lagoon, Tasmania, 17.II.1981, (3); *G. pedderensis* TMH D1123, Swampy Creek, Tasmania, 23.I.1970, (5); *G. fontanus* TMH D1740, Swan River, Tasmania, 20.II.1981, (5).

Vertebrae were not counted on the examples of *G. fontanus* used in the present study. Fulton, (1978) gave the range as 50–53.

Values of Student's T, using a pooled estimate of the variance, are listed in table 3 for the tabled body proportions when *G. niger* is compared with the other three species.

Size

The largest specimen examined in the present study was 105.2mmLS with the majority falling within the range 65–95mmLS.

Life History

In common with the other three species considered here, the life history of *G. niger* has not been studied, but females in the material examined showed developing eggs of rather less than 1.0mm

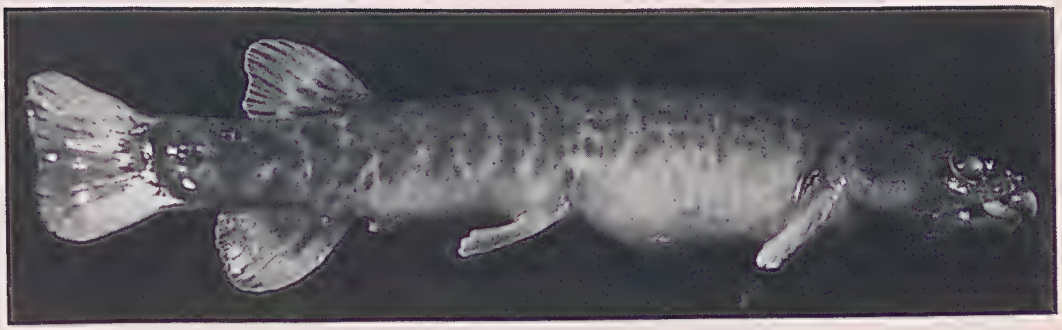

PLATE 1 — Galaxias niger n.sp. (holotype), Reservoir Lakes, southeastern Tasmania.

diameter which indicate a late winter or early spring spawning.

No evidence of a marine migratory phase in the life cycle was found, juveniles and adults were abundantly distributed throughout the two bodies of water that comprise the type locality. Large shoals of juveniles were observed in the shallows around the edges of the lakes while adults appeared to favour the deeper and more shaded areas.

There was also no evidence to suggest that *G. niger* shares the habitat with other galaxiid species.

Distribution

At present *G. niger* is known only from the type locality which is the principal source of the Picton River (fig. 1).

DISCUSSION

The meristic and morphometric data presented in tables 1–3 indicate that although the four species here considered are superficially similar there are nevertheless consistent and significant differences between them that appear to justify the retention of all as distinct species. The data furthermore indicate that the differences between *G. niger* and the other three species are equally as great, if not greater in some cases than the differences between the three species themselves as evidenced by the number of times the value of Student's T exceeds the 1% significance level (table 3).

Superficially, the colour pattern of *G. niger* although darker and more pronounced, is not dissimilar to two other Tasmanian species, *G. cleaveri* Scott and *G. brevipinnis* Gunther. However, the elongated body of *G. cleaveri* and the large paired fins and canine teeth of *G. brevipinnis* allow them to be readily distinguished from *G. niger*.

G. niger, *G. johnstoni*, *G. pedderensis* and *G. fontanus* each appear to be exclusively confined to one body of water, thus raising the question of how these distributions came about. In a previous study (Andrews, 1976), it was suggested that the Tasmanian distribution of *G. brevipinnis* could best be explained by the assumption that the species used its exceptional climbing ability to invade the upland regions following glacial withdrawal at the end of the Pleistocene. In the same study the ability of *G. brevipinnis* to move from one body of water to another was demonstrated by a population which showed evidence of making a juvenile upstream migration from one lake to another. Although the present day distribution of *G. brevipinnis*, the most widely distributed species in Tasmania, can be explained by this means, it appears unlikely to have applied to *G. niger*, *G. johnstoni*, *G. pedderensis* and *G. fontanus*.

Reservoir Lakes, the habitat of *G. niger*, are adjacent to another permanent water body, the Pigsty Ponds. Whereas the outfall from Reservoir Lakes flows north into the Picton River, the Pigsty Ponds form the source of the southeasterly flowing D'Entrecasteaux River. The two water bodies are separated by 0.3 km and a gentle slope which at times of high rainfall is crossed by numerous small temporary streams. The area, however, is evidently impassable to *G. niger*, as the Pigsty Ponds were found to be densely populated with tadpoles, a condition which in the author's experience is incompatible with the presence of galaxiid fishes. Similarly, *G. johnstoni* and *G. pedderensis* appear to be unable to either migrate or extend their habitat from one area to another despite the fact that there are continuous aquatic connections which would enable them to do so.

It is significant to observe that the areas inhabited by *G. niger*, *G. johnstoni and G. pedderensis* all exhibit abundant evidence of Pleistocene glaciation, (see Derbyshire *et al*, 1965) and it is possible that glacial activity may have influenced the distribution. McDowall and Frankenberg (1981) show the distribution of *G. olidus* as being widespread over southeastern Australia and if the similarity between the five species is indicative

TABLE 1
MERISTIC VARIATION IN FOUR SPECIES OF *GALAXIAS*

Species	*Dorsal rays*				*Anal rays*			*Pectoral rays*						
	7	8	9	10	9	10	11	10	11	12	13	14	15	16
G. niger n.sp.		1	13	6	3	12	5					16	21	2*
G. johnstoni			3	1	1	3				3	5			
G. pedderensis		1	4		1	4			1	7	1*			
G. fontanus	1	3	1		1	2	2	3	7					

* = absence of a fin in one specimen

	Ventral rays			*Vertebrae*									
	6	7	8	49	50	51	52	53	54	55	56	57	58
G. niger n.sp.	1	38	1									1	2
G. johnstoni		8						1	1		(+)		
G. pedderensis		10		1	2	2		1	1	1	(+)		
G. fontanus		10						see text					

(+) = Data from Andrews (1976)

of a common ancestor, then this common ancestor may have been distributed over southeastern Australia, including Tasmania, prior to the last glacial period. If those populations which occurred in the upland region developed cold tolerant forms then it is possible that they were able to survive the glacial period in a few areas to later remain as relict populations after glacial withdrawal.

G. niger ccurs in the headwaters of the Picton River, a tributary of the Huon drainage system, while *G. johnstoni* and *G. pedderensis* are found in the headwaters of the Derwent and Gordon River systems respectively (fig. 1). If a common ancestor is indeed the case with these species then it would appear to have been quite widely distributed in much the same way as *G. olidus* on the Australian mainland.

The exception to a glacial-related distribution would appear to be *G. fontanus*. However, as Fulton (1978) has pointed out, this species occurs in a virtual "desert" as far as native fish are concerned and it may be that this species, once established, has managed to survive due to lack of competition.

With the exception of *G. pedderensis*, which marginally shares its habitat with *G. parvus* Frankenberg, none of the species considered here has been found in sympatry with other galaxiid species. It seems therefore not improbable that other such populations may have existed in the past but subsequently been displaced by larger and more adaptable species, such as *G. brevipinnis*. Although Tilzey (1977) found that some galaxiid species could not survive in the presence of introduced salmonids, there has been too little study on the interactions of galaxiid fishes in the wild to enable this hypothesis to be tested.

ACKNOWLEDGEMENTS

I would like to thank Ms Maryanne Sawle of Sorell for bringing to my attention the species described here and Mr Alex Buchanan of the Tasmanian Herbarium for assistance with the collection of specimens.

TABLE 2
MORPHOMETRIC VARIATION IN FOUR SPECIES OF *GALAXIAS*
Numerator written as a percentage of denominator

	G. niger n.sp.				*G. johnstoni*				*G. pedderensis*				*G. fontanus*			
	Min.	$\bar{X}$	Max.	S.D.	Min.	$\bar{X}$	Max.	S.D.	Min.	$\bar{X}$	Max.	S.D.	Min.	$\bar{X}$	Max.	S.D.
HL/LS	20.3	21.7	22.9	0.76	21.7	22.0	22.4	0.30	21.3	22.6	24.8	1.25	21.4	23.7	24.8	1.22
S-DO/LS	69.4	72.6	75.1	1.40	67.6	69.8	71.5	1.50	65.7	66.9	68.9	1.20	69.1	70.5	71.3	0.80
S-VO/LS	48.5	51.3	53.8	1.41	52.0	54.0	55.9	1.67	50.9	52.6	54.4	1.19	50.7	52.8	54.9	1.60
PL/PB-VO	42.3	49.3	56.9	4.47	47.7	48.5	51.2	1.24	44.2	48.5	52.5	3.43	51.1	55.7	59.0	2.75
VL/VB-AO	48.0	54.0	62.9	3.64	50.0	54.7	59.7	3.69	60.3	65.5	74.1	4.41	58.2	63.6	73.6	5.55
DCP/LCP	42.0	49.8	61.2	4.89	42.7	48.0	54.8	4.33	38.7	40.2	44.5	2.11	48.0	54.7	60.2	4.42
LCP/LS	16.2	18.8	19.7	1.09	19.4	20.3	21.9	0.97	22.5	22.9	23.5	0.39	17.8	18.7	20.2	0.97
ED/HL	17.9	19.6	23.2	1.65	17.2	20.5	22.2	2.00	16.8	19.4	22.4	2.17	23.8	25.9	27.9	1.67
UJL/HL	42.6	45.4	50.8	1.99	37.4	40.0	44.3	2.80	39.2	42.0	45.4	2.19	40.8	44.8	49.2	3.13
LJL/HL	30.7	39.0	46.2	3.27	32.2	35.9	38.7	2.69	35.4	37.5	39.9	1.79	38.5	41.7	46.0	2.75
GW/HL	44.4	49.8	60.5	3.47	40.8	43.0	45.8	1.99	37.8	42.0	45.1	2.52	31.5	36.7	41.3	3.23
IW/HL	37.1	40.0	43.1	1.64	38.2	40.5	43.3	1.86	37.4	38.4	39.9	0.88	37.5	39.7	42.2	1.78
HW/HL	66.4	74.6	81.7	3.93	63.7	69.7	74.0	3.73	62.7	64.1	66.4	1.30	57.7	63.0	67.5	3.30

TABLE 3

Values of Student's T as a comparison of *G. niger* n.sp. with three other species of *Galaxias*..

Ratio	*G. johnstoni*	*G. pedderensis*	*G. fontanus*
HL/LS	1.07	*1.97*	**4.35*
S-DO/LS	*3.50	**8.03*	**3.09*
S-VOL/LS	*3.25	*1.83*	*1.97*
PL/PB-VO	0.34	*0.36*	**2.94*
VL/VB-AO	0.34	**5.81*	**4.51*
DCP/LCP	0.66	**4.15*	*1.96*
LCP/LS	2.46	**7.88*	*0.18*
ED/HL	0.93	*0.22*	**7.33*
UJL/HL	*4.39	**3.21*	*0.51*
LJL/HL	1.70	*0.95*	*1.64*
GW/HL	*3.64	**4.53*	**7.32*
IW/HL	0.53	*2.03*	*0.34*
HW/HL	2.20	**5.65*	**5.83*

* value exceeds 1% significance level

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OREOPORANTHERA, A NEW ZEALAND "ENDEMIC" PLANT GENUS DISCOVERED IN TASMANIA

by A.E. Orchard and J.B. Davies

(with one text-figure)

ORCHARD, A.E. & DAVIES, J.B., 1985 (31:vii): *Oreoporanthera*, a New Zealand "endemic" plant genus discovered in Tasmania. *Pap. Proc. R. Soc. Tasm.* 119:61–63. ISSN 0080–4703. Tasmanian Herbarium, GPO Box 252C, Hobart, Tasmania, and Department of Agriculture, Marine Board Building, Hobart, Tasmania.

Recent collections near Mt Anne in southwestern Tasmania have extended the known range of the previously monotypic New Zealand endemic genus *Oreoporanthera* to this island. The Tasmanian plants differ from New Zealand's *O. alpina* in a number of floral and vegetative characters and are considered to represent a new species *O. petalifera*. Like *O. alpina, O. petalifera* is found on calcareous montane outcrops and the two are clearly closely allied.

Key Words:- Poranthereae (Euphorbiaceae), *Oreoporanthera*, Tasmania.

INTRODUCTION

In 1969 Hutchinson provided a synthesis of his 50 year's study of the family Euphorbiaceae. He recognised and described 40 Tribes. One of the smaller ones was Tribe 9, Poranthereae Muell.-Arg. containing only the type genus *Poranthera* Rudge with 9 species, and the newly recognised monotypic genus *Oreoporanthera* Hutch. based on *Poranthera alpina* Cheesem. of New Zealand. *Oreoporanthera* was distinguished from *Poranthera* by being dioecious instead of monoecious, by having its flowers arranged singly in the axils of the upper leaves instead of in heads, by its strictly opposite leaves with strongly recurved margins, and by its flowers, which lacked petals in both sexes and a vestigial ovary in the males. The new genus has been accepted subsequently by Mark & Adams (1973) and (tentatively) by Moore & Irwin (1978).

Oreoporanthera alpina is confined to a small number of mountain tops in the northwestern corner of the South Island of New Zeland where it is described as coming from open subalpine communities between 1000 and 1800 m altitude amongst limestone, marble or granite rocks.

DESCRIPTION AND DISCUSSION

Recently, one of us (J.B. Davies) found a plant similar to *O. alpina* on karst formations on a ridge (known unofficially as the 'North East Ridge') of Mt Anne in southwestern Tasmania between 800–1000 m above sea level. The top of the ridge is predominantly covered by dwarf subalpine rainforest less than about 6 m in height, dominated by *Nothofagus cunninghamii, Richea pandanfolia* and *Athrotaxis selaginoides*. This dense vegetation is dissected by a series of knife-blade outcrops of dolomite and a number of deep sink holes. *Oreoporanthera* grows as mats up to about 0.2 m in diameter exploiting cracks and crevices on these exposed outcrops. Associated species include *Dichosciadium ranunculaceum, Oreomyrrhis gunnii, Senecio pectinatus* var. *pectinatus* and a number of ferns including *Cystopteris filix-fragilis, Grammitis armstrongii* and *Asplenium trichomanes*. Unusual grasslands develop on the steep slopes of the sinkholes. They are dominated by *Poa labillardieri* and include *Danthonia hibernae-fortunae, Poa gunnii, Agrostis billardierii* var. *filifolia, Agrostis aemula* and *Trisetum spicatum*.

Comparison of the Tasmanian specimens with descriptions, illustrations and specimens of *O. alpina* revealed that our plant, although very similar in many respects to the New Zealand species, differed in a number of characters. The habit of the plant is generally more lax with usually longer internodes and thinner stems which often lack the longitudinal flecks of purple pigmentation present in *O. alpina*. By contrast *O. alpina* has more erect stems, all except the youngest somewhat inflated or succulent, with the leaves usually more or less crowded towards the ends of the branches. The Tasmanian plants apparently die back each year to a small woody rootstock, whereas the stems of *O. alpina* seem more woody and possibly persist longer. The stipules of the New Zealand plant are more coriaceous than ours. However, the most important differences lie in the flowers. Like *O. alpina*, our plants are dioecious, but differ in that

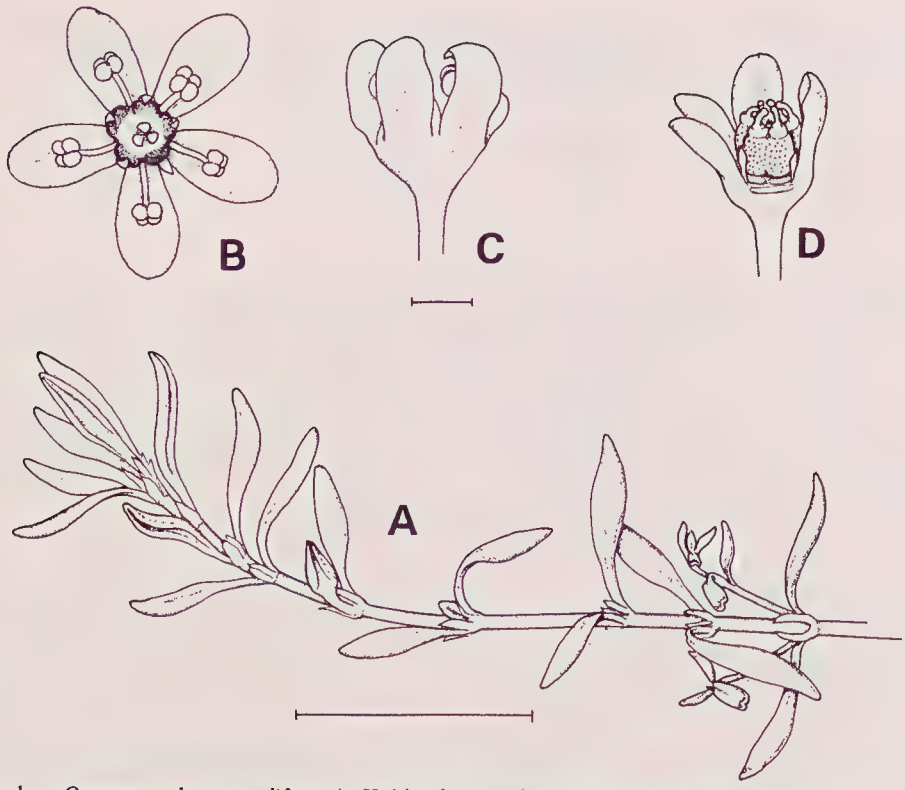

FIG. 1 — *Oreoporanthera petalifera*. A. Habit of vegetative branch. B. Male flower seen from above, showing vestigial ovary. D. Male flower with sepals closed. C. Female flower, one sepal removed, showing petals, and ovary at an early stage of development towards fruit. Bar scales represent 10 mm (A) or 1 mm (B–D). (A–C from Davies 31, D from Buchanan & Davies 3725).

both the male and female flowers possess small white lanceolate petals, shorter than the sepals. We believe that these differences justify recognition of the Tasmanian plants as a distinct species. described as follows.

Oreoporanthera petalifera Orchard & Davies, sp. nov.

Herbae perennes *O. alpinam* simulans, sed habitu laxiore, caulibus gracilioribus, stipulis mollibus albis, et petalis lanceolatis florum masculinorum et femineorum, differt.

Typus: J.B. Davies 31, N.E. ridge of Mt Anne, Tasmania, 31.xii.1984.

Holotypus: HO 88949. Isotypi: CHR, MEL.

Decumbent perennial herb; stems annual, dying back to a slightly woody base, 0.2–0.3 m long, 1 mm diam., freely branched, scrambling over rocks and adjacent plants. Leaves opposite, subglossy above, lanceolate, 6–7 mm long, 1.0–1.7 mm wide, tapering into a short petiole at base, margins revolute almost to the midrib. Stipules herbaceous, white, obliquely ovate to falcate, 0.8–1.1 mm long, 0.5 mm wide, degrading on older branches. Plants dioecious, flowers unisexual, borne singly in the axils of the upper leaves. Male flowers on pedicel 1.3–2.0 mm long; sepals 5, white with greenish central band, oblong to oblanceolate, 1.8–2.0 mm long, 1 mm wide, abruptly tapered to obtuse apex or rounded; petals 5, white, lanceolate, 0.6 mm long, 0.25 mm wide, erect, finally becoming incurved between stamens; stamens 5, opposite sepals, filaments 1.2 mm long, slightly incurved, terete, anthers yellow, 4-celled, depressed globular, 0.3 mm long, 0.4 mm diam., opening by terminal pores; ovary vestigial, 3-lobed, white to greenish, c. 0.3 mm diam.; disk green, 5-lobed, with one lobe at base of each petal. Female flowers on pedicel 1.6–2.5 mm long; sepals 5, greenish white, linear-oblong, 1.6–2.2 mm long, 0.6 mm wide, rounded at tip; petals 5, hyaline, linear to lanceolate, 0.4 mm

long, 0.15 mm wide; ovary globular 0.6 mm diam., styles divided to base and apparently 6; disk green, broadly 5-lobed. Fruit depressed globular 1.2 mm long, 2.0 mm diam., 6-seeded, explosively loculicidal, leaving a persistent columella on the pedicel/perianth remains. Seed pale orange brown with a white tesselated pattern superimposed, smooth.

Distribution

Known only from the dolomite ridge running north and northeast of Mt Anne in southwestern Tasmania at altitudes between 800 and 1000 m above sea level, but locally abundant. Flowering December, fruiting in June. Other specimens known: *Buchanan & Davies 3725*, north-east ridge of Mount Anne, 29.vi.1984 (HO); *Buchanan 5101, 5102, 5103, 5116, 5117, 5119,* north-east ridge of Mount Anne, 31.xii.1984 (HO, 5117 also CANB); *Davies s.n.,* Mt Anne, 18.vi.1984 (HO 78671).

STATUS OF THE GENUS *OREOPORANTHERA*

Discovery of this species makes a re-examination of the limits and status of the genus *Oreoporanthera* necessary. *O. petalifera* is clearly closely related to *O. alpina* yet it disagrees with Hutchinson's description of the genus in having *Poranthera*-like petals in the male and female flowers, and in having a distinct vestigial ovary in the male flowers. (In fact, Hutchinson was mistaken in believing that *O. alpina* lacked a vestigial ovary in the male flower. Although small, it is certainly present, and is clearly illustrated in Moore & Irwin (1978).) Furthermore Hutchinson's character of flowers solitary in the axils for *Oreoporanthera* vs in terminal heads for *Poranthera* seems to be only a matter of degree. In the *Poranthera* species that we have examined the terminal heads consist of tightly packed single flowers each subtended by a green leaf-like floral bract, and can consequently be interpreted as only condensed versions of the situation in *Oreoporanthera*.

However, despite these discrepancies, *Oreoporanthera* as a genus of two species can still be adequately separated from *Poranthera* s. str. on three characters: its dioecy, and the fact that its leaves are strictly opposite in arrangement and have strongly recurved margins. The specialised subalpine habitat favoured by the two *Oreoporanthera* species provides a confirmatory indication that they are different from species of *Poranthera* which (with the exception of *P. microphylla*) are predominantly lowland plants.

ACKNOWLEDGEMENTS

Mr. A.M. Buchanan (twice), Dr. B. Potts and Mr. N. Davidson accompanied J.B. Davies on the arduous trek up the North East Ridge where *Oreoporanthera* grows to collect material at the right stage of development for study. Material of *O. alpina* was kindly loaned for comparative study by the Herbarium, Botany Division, DSIR, Christchurch, New Zealand. Mr. D.I. Morris prepared the line drawings of *O. petalifera* and identified the grass species. The Botany Department, University of Tasmania, provided financial support for J.B. Davies' vegetation study in the area. The authors are grateful for the assistance received from all these sources.

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(accepted May 3, 1985)

OBSERVATIONS ON *CARCINONEMERTES* (NEMERTEA:CARCINONEMERTIDAE) ASSOCIATED WITH THE SMOOTH PEBBLE CRAB, *PHILYRA LAEVIS*.

by P.J. Bell and J.L. Hickman

(with three text figures)

BELL, P.J. & HICKMAN, J.L., 1985 (31:vii): Observations on *Carcinonemertes* (Nemertea:Carcinonemertidae) associated with the smooth pebble carb, *Philyra laevis*. *Pap. Proc. R. Soc. Tasm.*, 119:65–68. ISSN 0080-4703. Department of Zoology, University of Tasmania, Hobart, Australia.

The occurrence of a nemertine on the crab *Philyra laevis*, identified as a species of *Carcinonemertes* similar to *C. carcinophila imminuta* Humes, 1942, is recorded. The genus has not previously been reported from Australia. Notes are given on the larval, immature and adult stages.

Key Words: ***Carcinonemertes*** **(Nemertea),** ***Philyra*** **(Brachyura), Tasmania**

INTRODUCTION

Commensal or parasitic habits are uncommon within the phylum Nemertea. Few true relationships with a host organism have been established and these nemerteans have been found to exhibit physiological, behavioural and morphological adaptations correlating with their hosts way of life (Fleming and Gibson 1981).

The genus *Carcinonemertes* has been found to exhibit definite relationships with its crab hosts. The first actual observations of a direct nutritional and physiological dependence of the nemertean on the host was made by Wickham (1979a). He found *Carcinonemertes errans* feeding on the eggs of the Dungeness crab *Cancer magister* (Wickham 1979a).

The basic outline of the life history of *Carcinonemertes* has long been known. Juvenile worms grow to maturity and reproduce only on female crabs brooding eggs. The degree of infestation is extremely variable and can be very high. Humes (1942) recorded at least 1000 worms in the gill chambers of one crab and Pearse (1949) found an average of 83 worms per host.

Immature worms are generally found between the gill lamellae (Gibson 1972), but in some species they occur on the exoskeleton (Wickham 1979b; Roe 1979). Immature worms in the branchial chamber are encapsulated until the host becomes ovigerous. They then move to the host egg mass to mature. On attaining sexual maturity, *Carcinonemertes* deposits its eggs amongst the host's egg mass.

Once hatched, the larvae either remain amongst the host eggs and feed upon them or leave the host and, displaying positive phototaxic behaviour, swim towards the surface waters. The worms that remain on the original host return to the gill chamber when the eggs have hatched (Gibson 1972).

Within the genus *Carcinonemertes*, 5 species are currently recognised, one of which comprises two varieties. Several host species have been recorded, mostly belonging to the Brachyura (Fleming and Gibson 1981). There has been a single record of a host species within the Leucosiidae (Humes 1942) and *Carcinonemertes* has not been recorded from Australasian waters.

During a survey of parasites of the Smooth Pebble Crab, *Philyra laevis* (Bell) in southeastern Tasmania, by one of us (P.J.B.), worms ascribed to the genus *Carcinonemertes* were found to occur on crabs from several localities. Preliminary observations on these worms are presented in this paper.

MATERIAL AND METHODS

Two sexually mature worms (1♂, 1♀) found on an ovigerous *P. laevis* collected from Great Bay, Bruny Island, Tasmania on the 14th March 1982 were the only mature worms collected during the survey. Numerous immature nemertines were obtained from a sample of 57 crabs collected from Dru Point, Margate, Tasmania, over the period 15th August to 15th September 1982.

Infected and uninfected crabs used in experiments were maintained in filtered, aerated, sea water at 14-15°C. General morphological observations were made on live nemerteans slightly compressed under a coverslip supported with a little vaseline. All measurements were made on live material.

INCIDENCE

P. laevis occurs in shallow water on sands and mud flats throughout southern and south-eastern Tasmania. Specimens infected with *Carcinonemertes* were collected from Great Bay, Bruny Island, and Dru Point, Margate. Other localities at which infection was observed were Barnes Bay, Bruny Island, and Pipe Clay Lagoon.

A 100% infestation was found in the Dru Point population.

Gravid and immature worms were encountered on the host egg mass and immature worms were found on the gills of both male and female crabs. The maximum number of encapsulated worms found on the gills of a crab was 43 and the highest number of ensheathed worms found on a host egg mass was 21.

ADULT

The two sexually mature worms found were red in colour and coiled amongst the host's eggs mass. Each was enclosed in a mucous sheath attached at its anterior end to the sternum of the host. The sheaths were slightly longer than the worms and lacked lapilli (fig. 1a,b). Within the sheath enclosing the female were numerous eggs of the nemertine, 62 um in diameter, most of which were well developed and a few had hatched. The eggs of the host were well developed but none appeared to have hatched.

The following measurements (in microns) were made on these worms after they had been compressed: stylet + basis length, o 22, o 19; epidermis thickness, o 14.2, o 23.7.

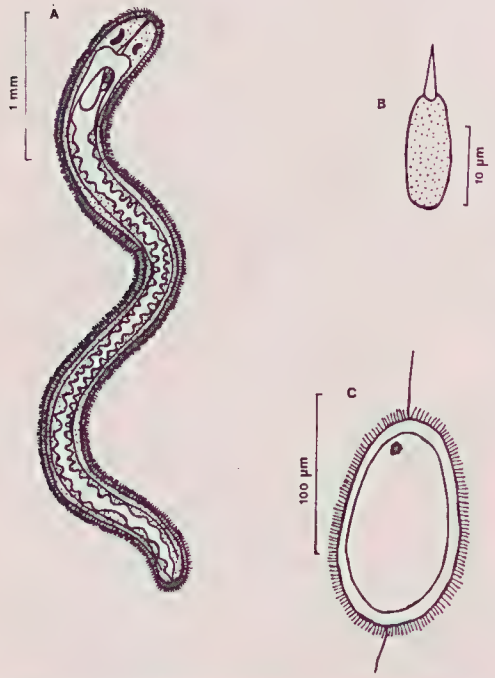

FIG. 1 — *Carcinonemertes sp.* A, adult from egg mass: B, stylet and basis; C, newly hatched larva.

LARVA

The newly hatched larva was ovoid and covered with long cilia (fig. 1c). It measured 130 x 52 um. The anterior and posterior cirri were 30 and 20 um long respectively. The thickness of the epidermis varied from 8 to 10 um. An elongated eyespot situated anteriorly, measured 4 um in length.

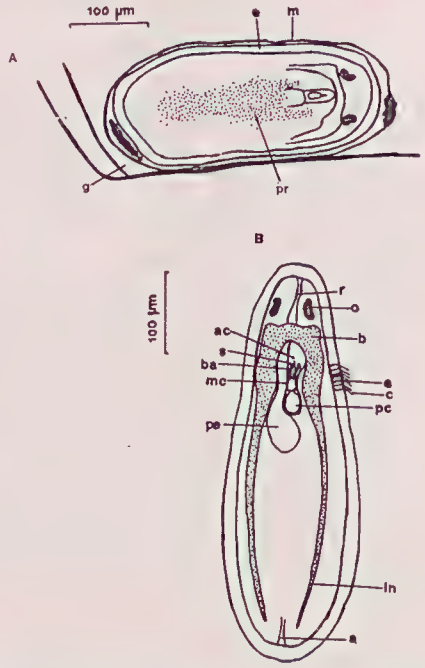

FIG. 2 — *Carcinonemertes sp.* A, encapsulated worm between gill lamellae; B, ventral view of worm removed from mucous capsule; a, anus: ac, anterior proboscis chamber: b, lobe of brain: ba, basis: c, cilia: e, epidermis: g, gill lamella: ln, lateral nerve cord: m, mucous sheath: mc, middle proboscis chamber: o, ocellus: pc, posterior proboscis chamber: pe, posterior part of oesophagus: pr, strongly pigmented region: r, rhynchodaeum.

IMMATURE WORMS

Immature worms (figs 2a,b) were found encapsulated in transparent mucous sheaths, attached to adjacent gill lamellae, in the branchial chamber of both male and female crabs. Capsules were found singly and tended to be more frequent towards the base of gill filaments. Little movement of worms was observed within the mucous capsules. However, if disturbed by the parting of adjacent gill lamellae the capsule would invariably rupture and the worm would immediately become active. Although the shape of the capsule was reasonably constant, the position of the worm within it was variable.

The number of worms present on the gills of individual crabs was highly variable (n, 57: x, 9.8: SD, 8.9: R, 0-43) but appears to show a significant increase with an increase in the carapace size of the host (fig. 3).

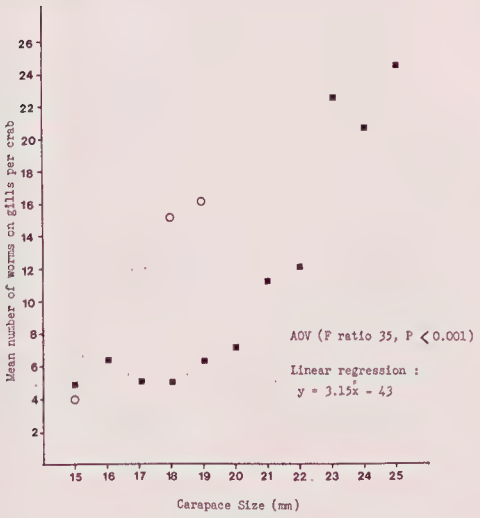

FIG. 3 — *Carcinonemertes sp.* Infection of *P. laevis* related to carapace size; solid squares - male crabs; open circles - female crabs.

The following measurements (in microns) were made on ten immature worms experimentally released from their mucous capsules and observed under slight coverslip pressure: length 520 (360 -825); width, 157 (75 - 281); basis, 17 (13 - 20) x 5.7 (4.3 - 6.4); stylet, 5.1 (3.8 - 6.4); epidermis, 12.2 (11.4 - 12.9); length of eye, 27 (20 - 35).

Unsheathed worms were found attached to the sternum and the ventral surface of the abdomen of non-ovigerous mature female crabs. These worms were not sexually mature and appeared to be dormant. The average length and width of these worms was 1.68mm and 0.4mm, respectively.

Five ensheathed worms, removed from a non-ovigerous host, were placed with eggs detached from an ovigerous crab in a crystal dish filled with fresh sea-water. After 6 hours, 2 worms had shed their mucous sheaths and were actively moving amongst the eggs. No feeding was observed and within 24 hours the worms had re-sheathed. These worms did not again exsheath when transferred to a fresh preparation of sea-water and host eggs.

Sexually immature worms both ensheathed and exsheathed were found in the region of the egg mass of crabs collected during August and September. Exsheathed worms were moving freely amongst the host's eggs. Ensheathed worms were attached to pleopods or the peripheral region of the ventral surface of the abdomen.

Five ensheathed worms removed from pleopods of ovigerous crabs had the following measurements (in microns): length, 3500 (1700 - 4600); width, 412 (348 -464); basis, 16.2 (14.3 - 18.5) x 5.7; stylet, 4.3.

DISCUSSION

Insufficient information on the morphology of the sexually mature adult prevents a specific identification of these worms being made using Humes' (1942) key to the species of *Carcinonemertes*. However many of the currently recognised species can be eliminated from consideration. Firstly, *C. epialti* Coe, differs from *Carcinonemertes sp.* in that the juvenile worms are found on the exoskeleton of the crab host and not on the gills (Kuris 1978), the eggs are oval, measuring 7 - 7.5 by 6 - 6.5 um (Roe 1979) and the basis and stylet are much larger, measuring 27-30 um and 12-15 um respectively (Humes 1942).

C. errans Wickham also differs from *Carcinonemertes sp.* in that juvenile worms occur on the carapace and not on the gills (Wickham 1980).

Adult worms of *C. mitsukurii* Takakura are brown, light yellow to milky white in colour, the basis is oval, the mean basis length is 27 um and the mean stylet length is 8 um (Humes 1942). *C. coei* Humes differs from *Carcinonemertes sp.* in that the mucous sheath is several millimetres longer than the body and lapilli, light brown in colour are widely scattered over the surface. The basis is swollen posteriorly and the stylet is longer.

The only other species of *Carcinonemertes* recorded is *C. carcinophila* which has two varieties, *C. carcinophila carcinophila* (Kolliker) and *C. carcinophila imminuta* Humes. The stylet and basis are generally larger in this species than they are in *Carcinonemertes sp.* However the mean sizes of the stylet and basis in *C. c. imminuta* are comparable

with those in *Carcinonemertes sp. C. c. imminuta* is known from only three adult worms which were collected off the egg mass of *Persephona punctata aquilonaris* from Grant Island, Louisiana. It is the only species so far recorded from a leucosiid. From the limited information available *Carcinonemertes sp.* shows a close resemblance in morphology, size and life history to *C. c. imminuta*. Further specimens and investigations are needed before a more definite specific identification can be made.

According to Humes (1942) Van Beneden, in a study of the European *C. carcinophila*, found a nemertean 3 - 4 cm long on an endopodite of a mature non-ovigerous crab. However, Humes found no worms on the endopodites of the mature non-ovigerous crabs he examined and concluded that post-reproductive worms probably return to the gills and regress sexually and in size but remain identifiable from immature worms. The sexually immature *Carcinonemertes sp.* found attached to the sternum and ventral surface of mature non-ovigerous *P. laevis* are easily distinguished from the immature worms found in the branchial chambers. They were never found in the branchial chamber and their presence on mature hosts throughout the non-ovigerous period suggests that after reproducing, *Carcinonemertes sp.* regresses sexually but remains attached to the ventral abdominal region and does not return to the gills.

There does not appear to be a great deal of host specificity within the genus *Carcinonemertes*. Some 20 hosts have so far been recorded for *C. carcinophila* alone. The majority of brachyurans recorded as hosts for *Carcinonemertes* belong to the Portunidae. Humes (1942) attributed this apparent specificity to the habit of these crabs to swim in large numbers near the surface of shallow water enhancing contact with the larvae of the nemertean. The leucosiid, *Philyra laevis* frequently occurs in large numbers in shallow tidal waters in sheltered bays, a habit which would likewise increase the possibility of infestation with *Carcinonemertes*.

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IDENTIFICATION OF THE HAIR OF TASMANIAN MAMMALS

by Robert J. Taylor

(with 5 text-figures and 10 plates)

TAYLOR, R.J., 1985 (31:vii): Identification of the hair of Tasmanian mammals. *Pap.Proc.R.Soc.Tasm.* 119:69–82. ISSN 0080–4703. Department of Zoology, University of Tasmania, Hobart, Tasmania, Australia.

Photographs of the hair structure of the five species of Tasmanian mammals (*Sarcophilus narrisii, Thylacinus cynocephalus, Bettongia gaimardi, Cercartetus lepidus* and *Pseudomys higginsi*) which have not been described by Brunner & Coman (1974) are presented. A key to the hair of forty Tasmanian mammals is provided to allow the identification of unknown samples. The key can be used in mammal surveys and in carnivore dietary studies.
Key Words:- marsupial hair, eutherian hair, Tasmania.

INTRODUCTION

Lyne & McMahon (1951) carried out a preliminary investigation of the structure of the hair of Tasmanian marsupials. Their aim was to investigate the taxonomic significance of hair structure but they were unable to achieve their objective of constructing a key to enable the identification of the hair of different species. They also did not present any data for the eutherian mammals in Tasmania. Brunner & Coman (1974) refined the techniques of hair identification and provided photographs of hair structure which could be used to identify the hair of mammals occurring in Victoria. Similar photographs have also been provided for mammals occurring in the south of Western Australia (Valente & Woolley 1982). The ability to identify hair samples has proved to be an invaluable tool in dietary studies of carnivores (Brunner, Lloyd & Coman, 1975, Jones & Coman 1981) and in mammal surveys, where hair traces found in hair sampling tubes (Suckling 1978) or in predator scats (Brunner, Amor & Stevens 1976) may be the only method of detecting the presence of a species.

In this paper data are presented on the hair structure of five species of mammals occurring in Tasmania which have not been described by Brunner & Coman (1974). A key is also provided to allow the hair of forty Tasmanian mammals to be identified. This study was undertaken because of the need to identify hair samples obtained during survey work and carnivore dietary studies conducted by members of the Zoology Department at the University of Tasmania.

HAIR IDENTIFICATION

Cross-sections, whole mounts and scale casts were prepared using the techniques outlined in Brunner & Coman (1974). Only terrestrial mammals were included in the study (i.e. bats and seals excluded). Photographs of the hair structure of the five native species present in Tasmanian which are not illustrated in Brunner & Coman (1974) (i.e. *Sarcophilus harrisii, Thylacinus cynocephalus, Bettongia gaimardi, Cercartetus lepidus* and *Pseudomys higginsi*) are given in Plates 1–10. The magnification for cross sections is approximately 425, and for whole mounts and scale patterns is 270. Terminology used to describe hair structure follows Brunner & Coman (1974).

Brunner & Coman (1974) and Valente & Wooley (1982) both arranged species into groups with similar structure and relied on a visual comparison between unknown samples and the photographs provided to key out hair. Brunner & Coman (1974) also provided a diagnostic feature for each species, wherever possible. In this paper the key has been made more dichotomous than in the other two studies (*op. cit.*).

KEY TO THE HAIR OF TASMANIAN MAMMALS

Initial separation of groups is based on the cross-sectional appearance of primary guard hairs.

A. Predominantly circular in cross-section ..... GROUP 1
B. Predominantly oval in cross-section ..... GROUP 2
C. Predominantly oblong in cross-section ..... GROUP 3

D. Predominantly eye or lemon-shaped in cross-section ..... GROUP 4
E. Predominantly reniform or concavo-convex in cross-section ..... GROUP 5
F. Predominantly dumb-bell-shaped in cross-section ..... GROUP 6
G. Predominantly flattened or cigar-shaped in cross-section ..... GROUP 7

Group 1

1. Maximum diameter of hair less than 40μm ..... *Cercartetus nanus* and *C. lepidus*
   Maximum diameter of hair greater than 40μm 2
2. All hairs either black or white ..... *Sarcophilus harrisii*
   Other colours preent 3
3. Orange-brown pigment granules present around the medulla of many of the guard hairs (unless only belly fur or hairs from the white spots present in sample) ..... *Dasyurus maculatus*
   Only dark pigment granules present around medulla of many of the guard hairs (unless only belly fur or hairs from the white spots present in sample) ..... *Dasyurus viverrinus*

Group 2

1. Medulla much reduced or absent 2
   Medulla prominent 3
2. Very wavy hair; maximum diameter of hairs less than 60μm ..... *Ovis aries*
   Bristle hairs; maximum diameter of hairs up to 220μm ..... *Sus scrofa*
3. Very large medulla ..... *Dama dama*
   Medulla not large 4
4. Maximum diameter of hairs less than 75μ 5
   Maximum diameter of hairs greater than 75μm 6
5. Maximum diameter of hairs up to 40μm; cortex narrower than in *Antechinus* (see Brunner & Coman 1974, pages 62, 64, 68) ..... *Sminthopsis leucopus*
   Maximum diameter of hairs up to 70μm; cortex wider than in *Sminthopsis* ..... *Antechinus swainsonii* and *A. minimus*
6. Underhairs have narrow cortex ... *Felis catus*
   Cortex of underhairs is medium or large ... 7
7. Spindle-shaped aggregations of pigment granules present in cortex (see Brunner & Coman 1974, page 97) ..... *Bos taurus*
   No spindle-shaped aggregations of pigment granules present in cortex 8
8. Medulla of guard hairs is widest in proximal one-third ..... *Equus caballus*
   Medulla of guard hairs is widest in distal half ..... *Canis familiaris*

Group 3

1. Medulla reduced or absent 2
   Medulla prominent 3
2. Hairs usualy less than 3 cm in length; no medulla; maximum diameter of hairs up to 350μm ..... *Tachyglossus aculeatus*
   Many hairs greater than 3 cm in length; small medulla present in some hairs in cross section; maximum diameter of hair up to 250μ ..... *Vombatus ursinus*
3. Medulla with characteristic lattice pattern (see Brunner & Coman 1974, page 127); length to breadth ratio of shield region of guard hair in cross-section usually 2.5 or greater ..... *Hydromys chrysogaster*
   Medulla lattice, if present, unlike that in *Hydromys*; length to breadth ratio of cross-section of hairs less than 2.5 4
4. Scale pattern on primary guard hair is near or close irregular wave; hairs generally less than 25mm long; hair is brown at base, pale sandy colour on upper half with a brown tip or all of hair a pale sandy colour ..... *Thylacinus cynocephalus*
   If wave scale pattern is present then it is regular (not irregular); guard hairs usually greater than 25mm in length (except in some *Bettongia*); base of hair grey, or if brown then hairs longer than 25mm 5
5. Many hairs with obvious white bands; diameter of primary guard hairs generally less than 75μm ..... *Macropus giganteus*
   Hairs without obvious white bands; maximum diameter of primary guard hairs greater than 75 μm 6
6. Base of hair grey brown, changing to brown with white band and brown or black tip (or hair all white) ..... *Macropus rufogriseus*
   Base of hair light grey 7
7. Underhairs oval in cross section ..... *Thylogale billardierii*
   Underhairs circular in cross section 8
8. Larger guard hairs and overhairs have a more oval or slightly reniform appearance in cross section in comparison with *Potorous* ..... *Bettongia gaimardi*
   Larger guard hairs and overhairs have a moe oblong appearance in comparison with *Bettongia* ..... *Potorous tridactylus*

Group 4

1. Diameter of hairs usually 20μm or less; maximum width 30μm ..... *Petaurus breviceps*
   Many hairs greater than 30μm wide 2
2. Maximum diameter of hairs 50μm; hairs are circular in cross section near base ..... *Pseudocheirus peregrinus*
   Maximum diameter of hairs 70μm; hairs are eye-shaped or oval in cross section near base ..... *Trichosurus vulpecula*

Group 5

1. Hairs with divided medulla 2
   Hairs with bilobed or large medulla 3
2. Maximum diameter of hair up to 180μm; appearance of concave depression in cross-section is shallower than in *Isoodon* (see Brunner & Coman 1974, pages 140 and 144) ..... *Perameles gunnii*
   Diameter of many hairs greater than 200μm; concave depression on hairs much more prominent than in *Perameles* .... *Isoodon obesulus*
3. Primary guard hair at widest point tending to be more reinform than concavo-convex in cross section 4
   Primary guard hair at widest point tending to be more concavo-convex than reinform in cross-section 5
4. Maximum diameter of hairs up to 40μm ..... *Pseudomys novaehollandiae*
   Maximum diameter of hairs greater than 40μm ..... *Pseudomys higginsi*
   Mastacomys fuscus
5. *Maximum diameter of hairs up to 50μm* ..... *Mus musculus*
   Maximum diameter of hairs greater than 50μm 6
6. Proximal half of primary guard hair is usually dark grey and is noticably thinner than in the introduced rats (see Brunner & Coman 1974, pages 146, 148 and 152) .... *Rattus lutreolus*
   Proximal half of primary guard hair is usually white or sometimes very light grey 7
7. Cross section of primary guard hairs is almost cigar-shaped ..... *Rattus norvegicus*
   Cross section of primary guard hair not tending to cigar-shape ..... *Rattus rattus*

Group 6

1. Scalloped medulla pattern (see Brunner & Coman 1974, page 167); diameter of many hairs greater than 150μm ..... *Capra hircus*
   Multiserial medulla pattern; maximum diameter of hairs up to 150μm 2
2. Scale pattern in shield region of primary guard hair is more irregular than in *Oryctolagus* (see Brunner & Coman 1974, pages 169 and 171) ..... *Lepus europaeus*
   Scale pattern in shield region of primary guard hair is regular ..... *Oryctolagus cuniculus*

Group 7

1. ..... *Ornithorhynchus anatinus*

DISCUSSION

The first step in identifying an unknown hair sample is to classify the appearance of the primary guard hairs in cross section. The hair to be identified should thus be positioned so as to include a cross section of the primary guard hair at its widest point. In some predator scats, because the hair has been well masticated, it is not possible to select a tuft of hair. In this case several sections should be made so as to obtain a representative sample of cross-sectional shapes. Only photographs of the hair of Tasmanian mammals that are not illustrated in Brunner & Coman (1974) are given in this paper. Thus the present paper needs to be used in conjunction with Brunner & Coman (1974) in order to identify a sample of hair. It shold be noted that the key is based on the structure of hairs found on the main pelage. Hair from the extremities can sometimes differ from that on the main pelage and hence it is important to have a set of skins available for reference.

I have classified the hairs of *Vombatus ursinus, Macropus giganteus, M. rufogriseus, Thylogale billardierii, Bettongia gaimardi* and *Potorous tridactylus* as having a predominantly oblong appearance in cross-section rather than an oval appearance as did Brunner & Coman (1975). The interpretation of the difference between these two groups is rather subjective; however, Valente & Woolley (1982) also classified the hair of the Macropodoidea as having an oblong appearance. *Pseudomys novaehollandiae* was placed in the oblong group by Brunner & Coman (1974) whereas I have placed it in the group with a concavo-convex appearance. The hair of *P. novaehollandiae* in cross-section has a very similar appearance to that of *Mastacomys fuscus* which Brunner & Coman (1974) placed in the concavo-convex group. The hair of the other member of the genus *Pseudomys* in Tasmania (*P. higginsi*) also has hair with a concavo-convex appearance in cross-section.

It has not been possible to differentiate the hair of all the species of mammals occurring in

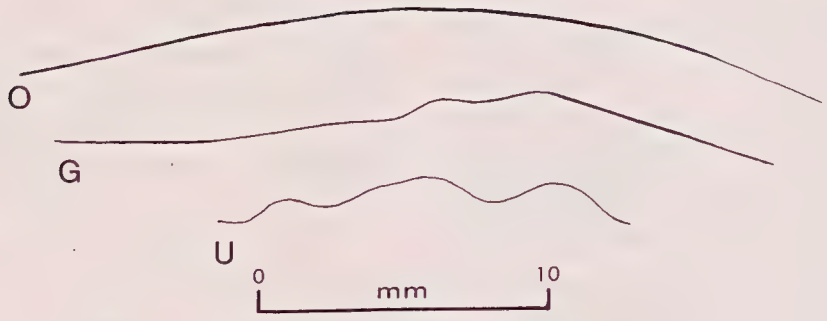
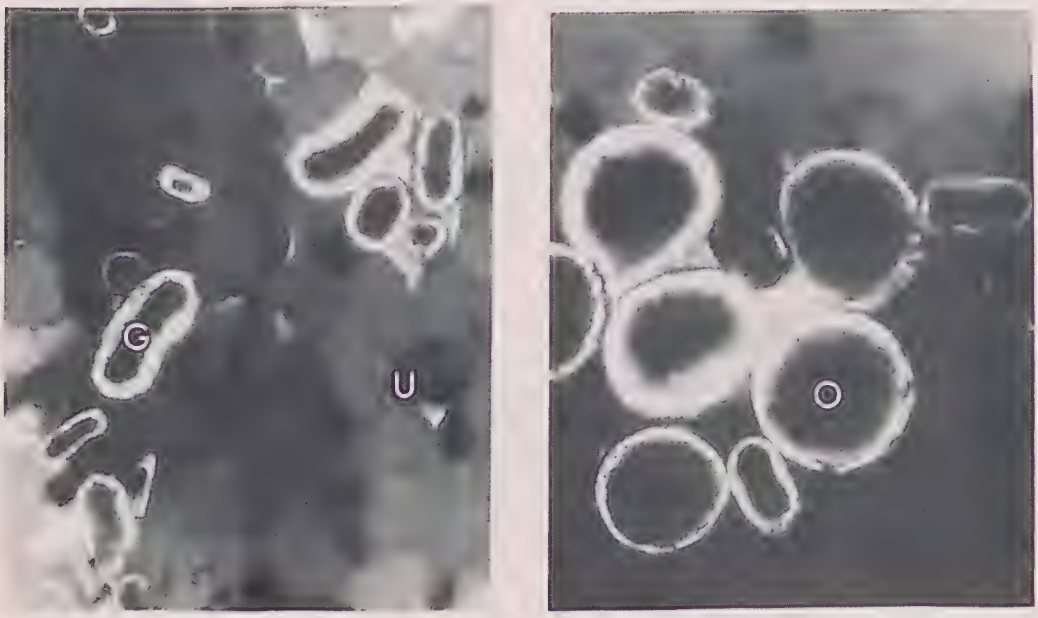


FIG. 1 — *Pseudomys higginsi* Hair profiles: 0 = over hair; G = guard hair; U = under hair.



A B

PLATE 1

PLATE 1 — Figures A, B: cross-sections of hairs of *Pseudomys higginsi.*

PLATE 2 *(facing)* — Figures A to D: whole mounts of hairs of *Pseudomys higginsi.* A, under hair in proximal (left) and distal (right) regions; B, small guard hair in distal region; C, primary guard hair in proximal region; D, primary guard hair in shield region.

Figures E to I: scale patterns of hairs of *Pseudomys higginsi.* E, under hair in proximal region; F, under hair in distal region; G, primary guard hair in proximal region; H, primary guard hair in mid-shaft region; I, primary guard hair in distal region.

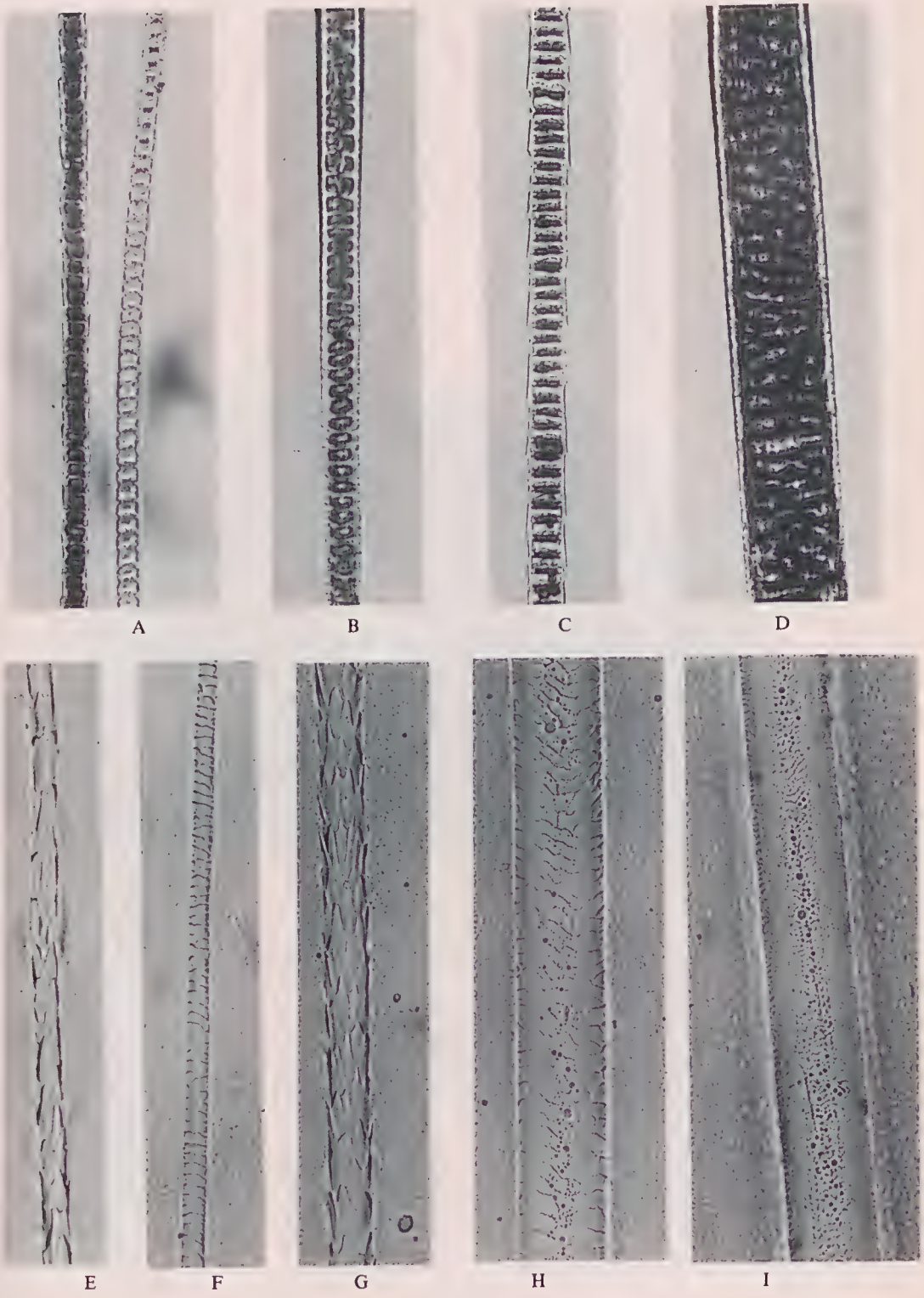


PLATE 2

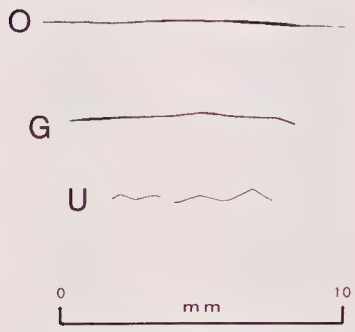


FIG. 2 — *Cercartetus lepidus* Hair profiles: 0 = over hair; G = guard hair; U = under hair.

PLATE 3

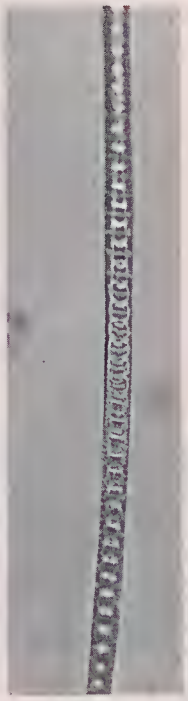
PLATE 3 — Cross-sections of hairs of *Cercartetus lepidus.*

PLATE 4 *(facing)* — Figures A to E: whole mounts of hairs of *Cercartetus lepidus.* A, guard hair in proximal region; B, guard hair in mid region; C, guard hair in distal region; D, primary guard hair in proximal region; E, primary guard hair in shield region.

Figures F to H: scale patterns of primary guard hairs of *Cercartetus lepidus.* F, proximal; G, transition between shaft and shield region; H, distal.

A

B

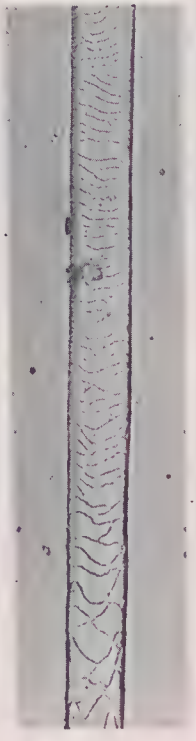


C

D

E

F



G

H

PLATE 4

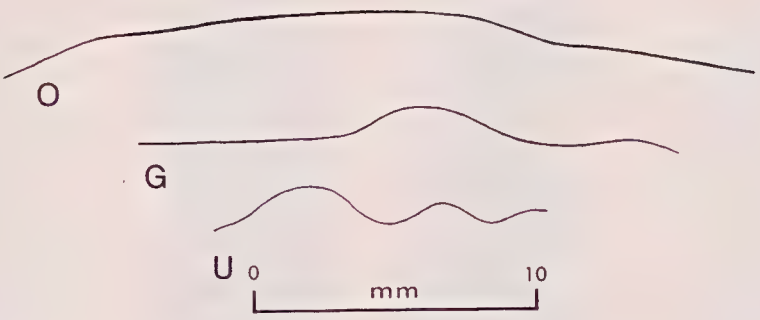


FIG. 3 — *Thylacinus cynocephalus*. Hair profiles: 0 = over hair; G = guard hair; U = under hair.

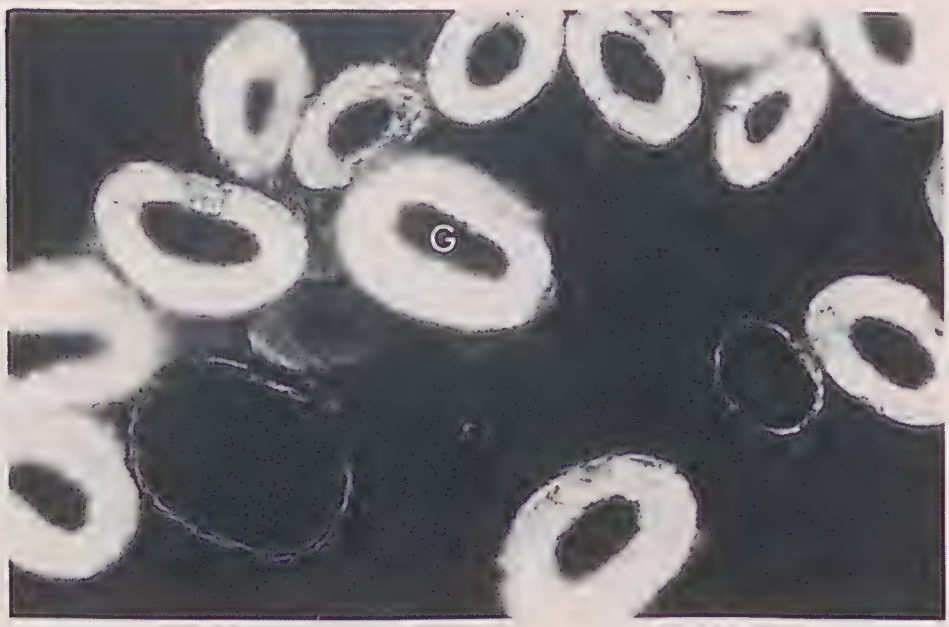


PLATE 5

PLATE 5 — Cross-sections of hairs of *Thylacinus cynocephalus*.

PLATE 6 *(facing)* — Figures A to D: whole mounts of hairs of *Thylacinus cynocephalus*. A, under hair in proximal region; B, under hair in distal region; C, primary hair in proximal region; D, primary guard hair in shield region.

Figures E to H: scale patterns of hairs of *Thylacinus cynocephalus*. E, under hair in proximal region; F, under hair in distal region; G, primary guard hair in proximal region; H, primary guard hair in mid-shaft region.

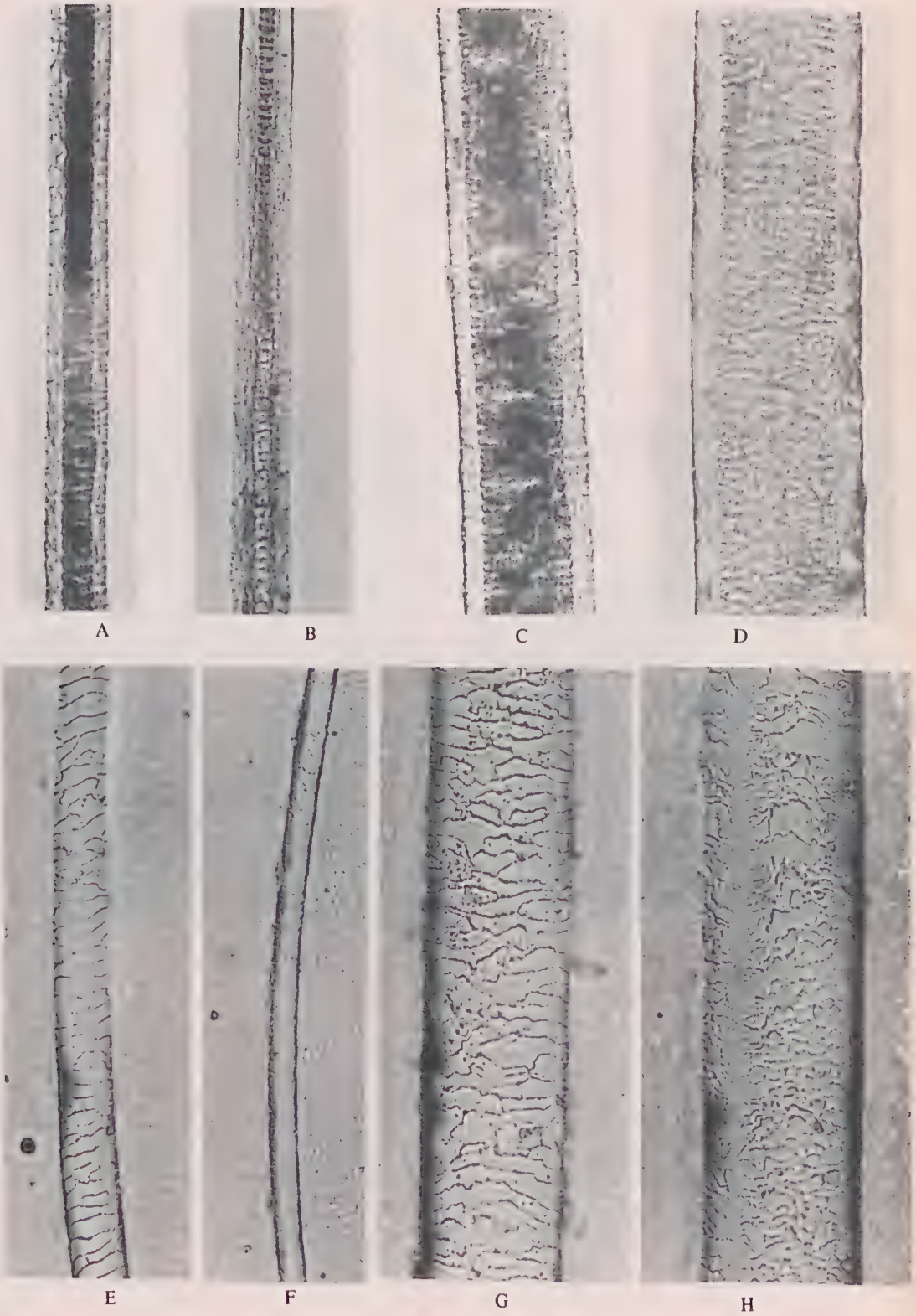


PLATE 6

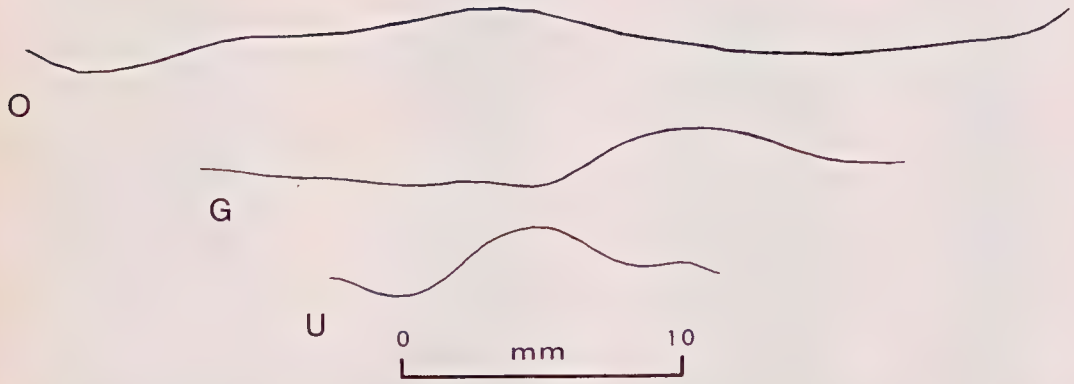
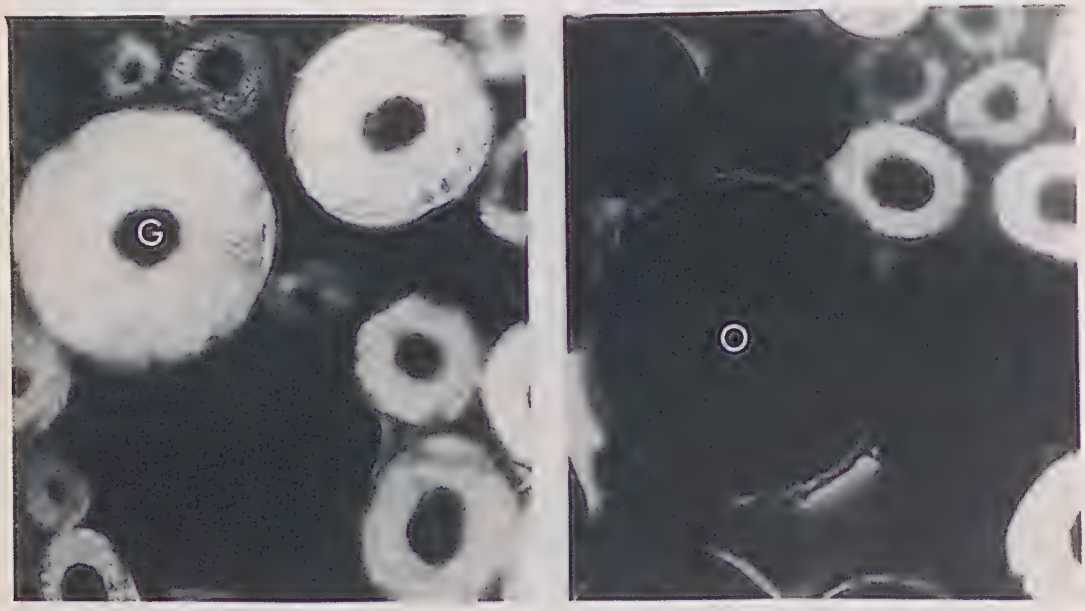


FIG. 4 — *Sarcophilus harrisii.* Hair profiles: 0 = over hair; G = guard hair; U = under hair.



A B

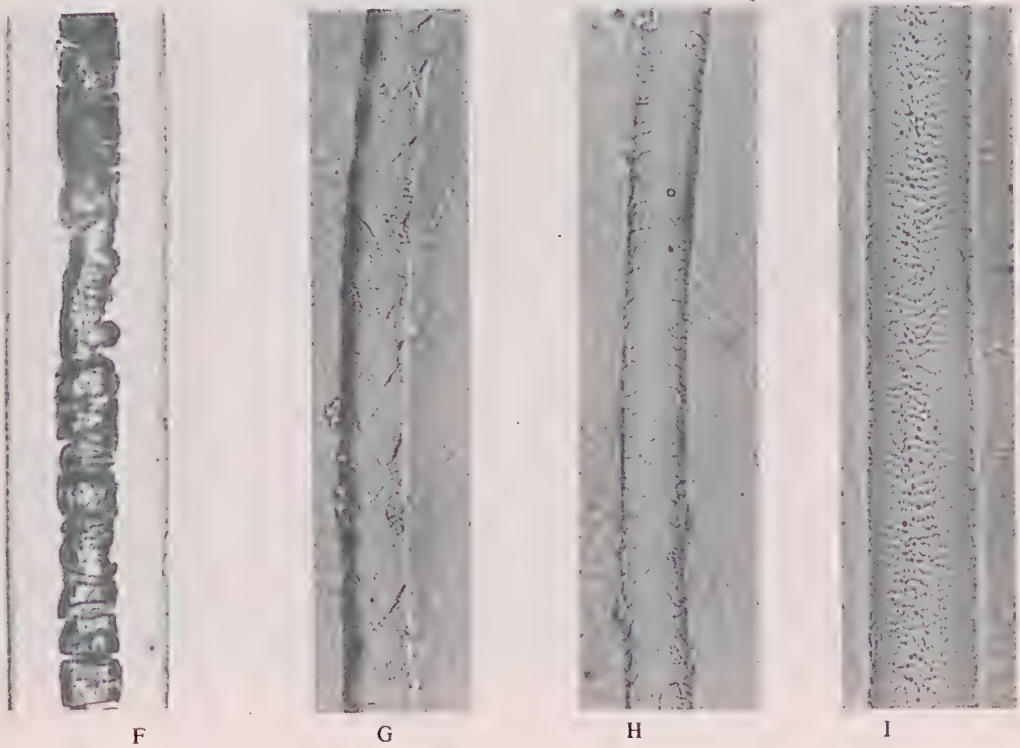
PLATE 7

PLATE 7 — Figures A, B: Cross-sections of hairs of *Sarcophilus harrisii.*

PLATE 8 *(facing)* — Figures A to F: whole mounts of hairs of *Sarcophilus harrisii.* A, under hair in proximal region; B, under hair in distal region; C, guard hair in proximal region; D, guard hair in mid-shaft region;E, guard hair in distal region; F, primary guard hair (white) in distal region.

Figures G to I: scale patterns of hairs of *Sarcophilus harrisii.* G, under hair in proximal region; H, under hair in distal region; I, predominant pattern along the length of the primary guard hair.

A B C D E



F G H I

PLATE 8

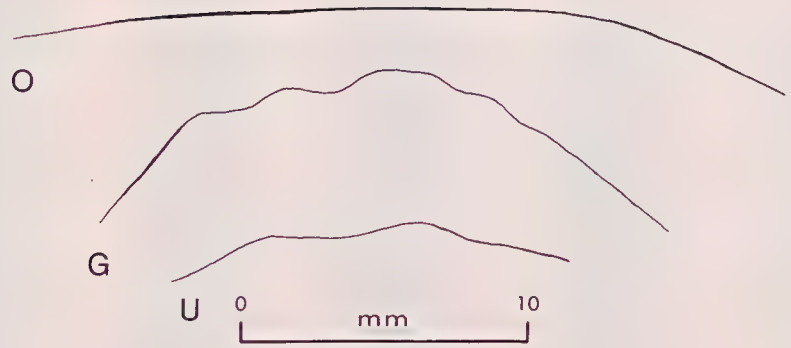


FIG. 5 — *Bettongia gaimardi.* Hair profiles: 0 = over hair; G = guard hair; U = under hair.

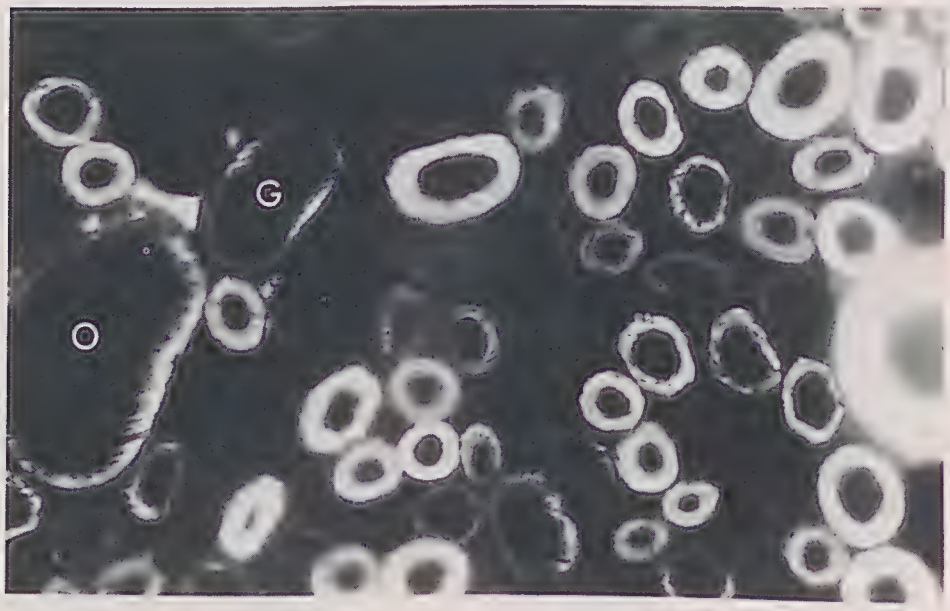
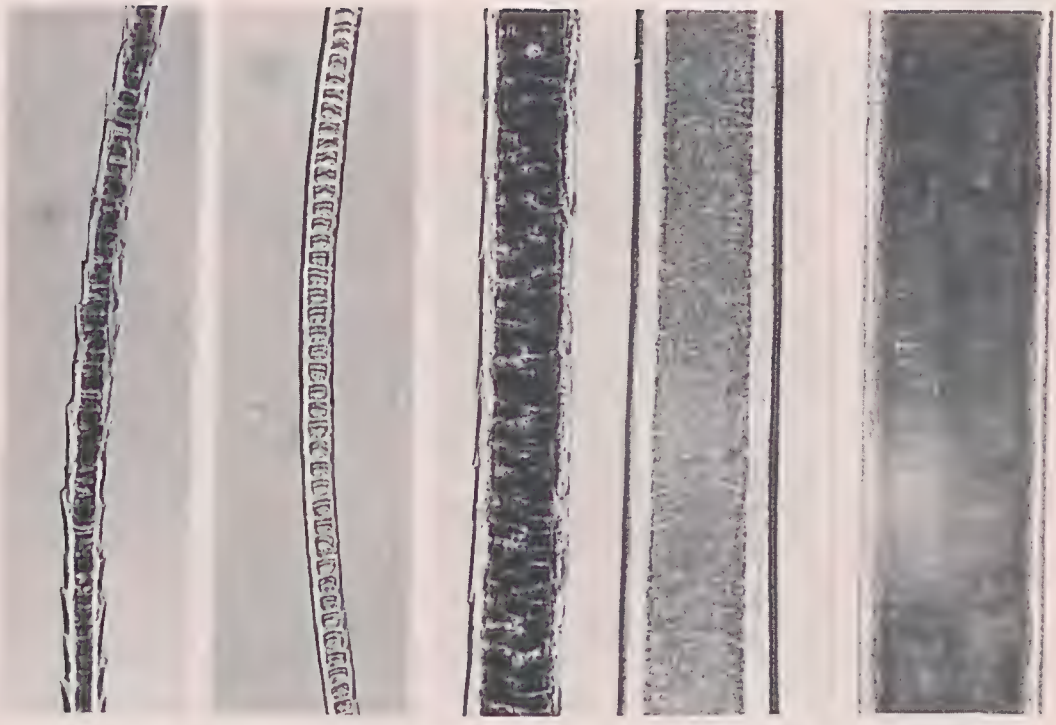


PLATE 9

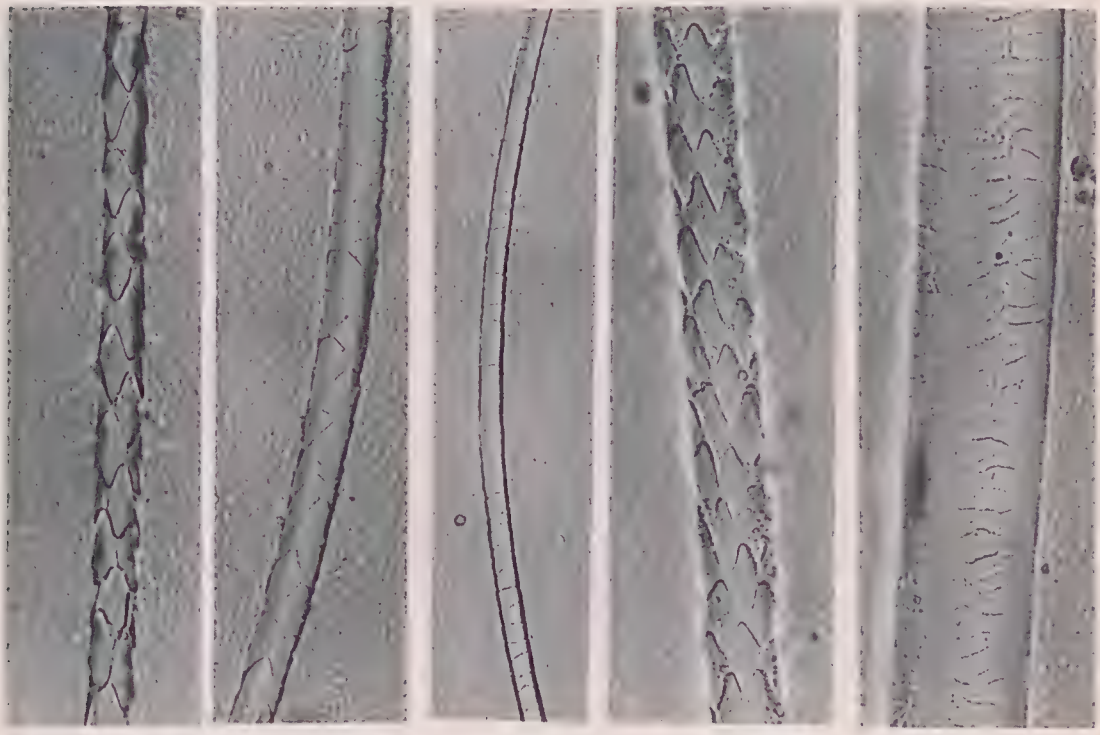
PLATE 9 — Cross-sections of hairs of *Bettongia gaimardi.*

PLATE 10 *(facing)* — Figures A to D: whole mounts of hairs of *Bettongia gaimardi.* A, under hair in proximal region; B, under hair in distal region; C, guard hair in proximal (left) and distal (right) regions; D, primary guard hair in shield region.

Figures E to I: scale patterns of hairs of *Bettongia gaimardi.* E, under hair in proximal region; F, under hair in mid-shaft region; G, under hair in distal region; H, primary guard hair in proximal region; I, primary guard hair in distal region.



A B C D



E F G H I

PLATE 10

Tasmania. Some closely related species are difficult to distinguish from one another. These are: *Antechinus swainsonii* and *A. minimus; Cercartetus nanus* and *C. lepidus*, although the hair of *C. nanus* is probably slightly longer and wider than that of *C. lepidus*; and *Pseudomys higginsi* and *Mastacomys fuscus*.

In Victoria analysis of the hair in predator scats has proved to be a useful means of assessing the distribution and abundance of *Mastacomys fuscus* (Brunner & Bertuch 1976). It was found in this study that *Pseudomys higginsi*, an endemic Tasmanian species, has hair which is difficult to separate from *M. fuscus*. This unfortunately limits the use of this technique as an aid in determining the status of this species in Tasmania. On the other hand the hair of *Thylacinus cynocephalus* was found to be distinguishable from other species and thus could be used in a search for this species.

Bats and seals were not included in this study as it was thought that these animals would only very rarely be present in predator scats. Dead seals may be occassionally scavenged by predators in coastal aras. Bats may be preyed upon by birds (Young 1980), and Maddock (1983) claims that *Nyctophilus geoffroyi* is frequently taken by domestic cats. The hair of bats can be easily identified by their characteristic scale patterns (see Brunner & Coman 1974, pages 44–53).

ACKNOWLEDGEMENTS

I would like to thank Phil Andrews and Catherine Medlock (Tasmanian Museum), Bob Green (Queen Victoria Museum), Dave Rounsevell and Greg Hocking (Tasmanian National Parks and Wildlife Service) and Ron Mawbey, Wayne Kelly, Nick Savva and Randy Rose (University of Tasmania) for the provision of hair samples. Hans Brunner provided helpful comments on a draft of the paper.

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(accepted May 10, 1985)

LATE PLEISTOCENE MARINE SEDIMENTS AND FOSSILS FROM MUSSEL ROE BAY, NORTHEASTERN TASMANIA

by Peter Baillie, Elizabeth Turner, and Patrick G. Quilty

(with four text-figures)

BAILLIE, P., TURNER, E. & QUILTY, P.G., 1985 (31:vii): Late Pleistocene marine sediments and fossils from Mussel Roe Bay, northeastern Tasmania. *Pap. Proc. R. Soc. Tasm.* 119:83–87. ISSN 0080–4703. Geological Survey of Tasmania, Tasmanian Museum and Art Gallery and Antarctic Division, Hobart, Tasmania, Australia.

Foraminifera- and mollusc-bearing estuarine sediments were encountered in one of a series of auger holes drilled in Late Pleistocene interglacial sands at Mussel Roe Bay, northeastern Tasmania. It is proposed that the estuary formed behind a bay-mouth barrier similar to that presently occurring between Mussel Roe Bay and Great Mussel Roe Bay.

Key Words: Late Pleistocene, estuarine sediments, NE Tasmania.

INTRODUCTION

Seaward-sloping coastal sand plains are distributed widely in northeastern Tasmania and occupy former large coastal embayments (Bowden 1978). The lithology of these deposits ranges from well-sorted coarse quartz sand, through finer sand and poorly-sorted sandy clay to sporadic beds of clay (Baillie in McClenaghan *et al.* 1982). Although fragmental mollusc shells (Baillie, *op.cit.*) and indeterminate sponge spicules (Bowden, *op.cit.*) have been recovered from the deposits at various localities between Bridport and Tomahawk (fig. 1),

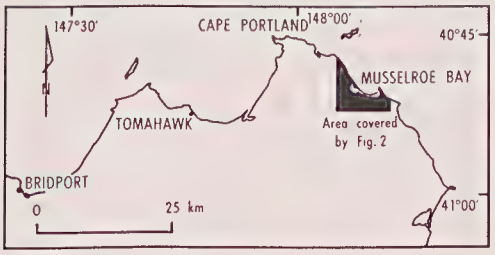

FIG. 1 — Locality Map

it has generally been assumed that well-preserved faunas have not been found because of the acid (pH 4.5–6.5) nature of the groundwater (Bowden, *op.cit.*; Colhoun *et al.*, 1982).

The age of the sand bodies has not been conclusively proved but a Last Interglacial age is probable (Bowden, *op.cit.*; van de Geer *et al.*, 1979).

It is the purpose of this paper to describe a Late Pleistocene foraminifera- and mollusc-bearing deposit from Mussel Roe Bay and to attempt a reconstruction of the palaeogeography of the area at the time of deposition of the sediments.

STRATIGRAPHY

The geology of the area and location of auger drill holes are shown as figure 2. Basement consists of psammites and pelites of the Early Palaeozoic Mathinna Beds which have been intruded by Devonian granitoids of the Eddystone Batholith (Baillie 1984). Northeast of Mussel Roe Bay a complete but attenuated sequence of Permian sedimentary rocks (Baillie 1983) overlies the granite, and has been intruded by Jurassic dolerite sheets and by minor intrusions of Cretaceous shoshonitic rocks.

Quaternary sand bodies are found in coastal areas, in particular, below a sharp break of slope at about 30 metres (fig. 3). A line of auger holes was drilled in November 1983 in an attempt to gain a better understanding of the Quaternary stratigraphy, and to test the possibility that the sands which form the bulk of the coastal sand plains are marine. The stratigraphy of the five auger holes is shown as figure 4.

Late Pleistocene marine and estuarine sands

Holes 1, 2, 3 penetrated sequences of poorly-sorted, generally negatively-skewed, medium to coarse quartz sands, and finer sediments with variable clay content, Because of difficulties in obtaining undisturbed samples from auger holes, assessment of the degree of sorting in the original

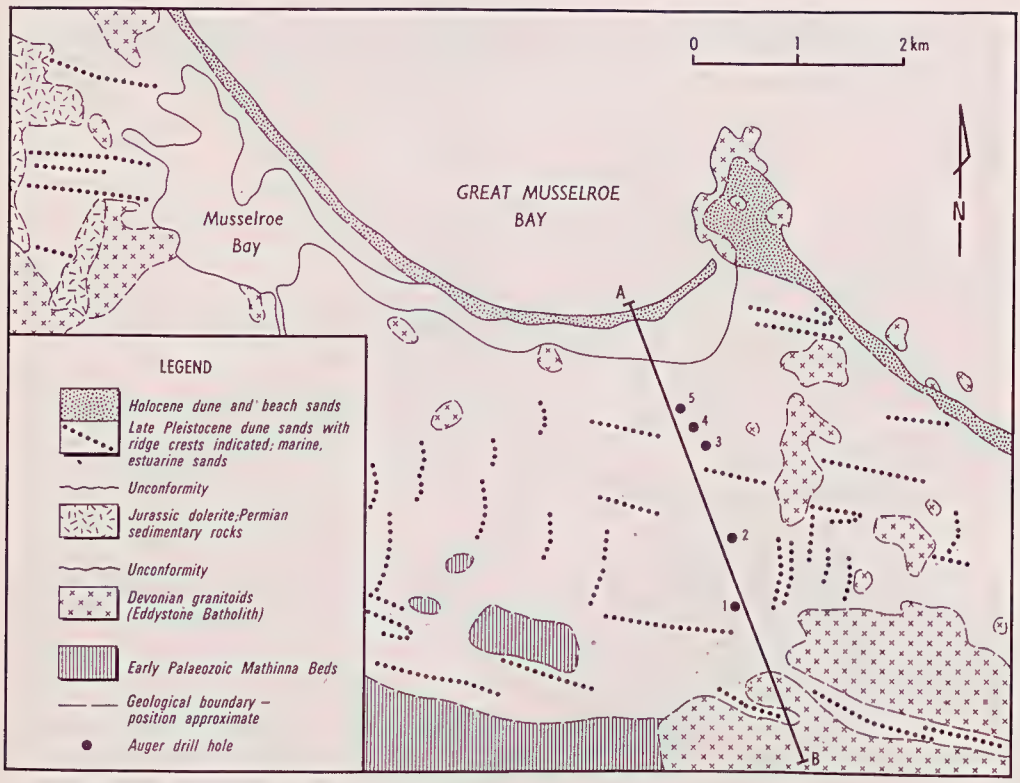

FIG. 2 — Generalised geology of the Mussel Roe Bay area (after Baillie, 1984)

deposits is uncertain. The upper 4 m in Hole 4 consisted of poorly-sorted (but clean), negatively-skewed, medium-coarse quartz sands. The lower 4 m of sediment in this hole consisted of black or dark-gray, shell-bearing, poorly-sorted, medium quartz sand. In Hole 5, from 2–21 m below the collar the sequence consisted of poorly-sorted, negatively-skewed, medium-coarse quartz sand. Indeterminate shell fragments were found in a sample from 8.5 m. In all holes drilled a podsol soil-type was developed in the upper 1–2 m.

In the Stumpys Bay area, some 10 km southeast of Mussel Roe Bay, well-preserved ridges are developed on deposits similar to those drilled at Mussel Roe Bay. The ridges are composed of well-rounded coarse sand and are oriented sub-parallel with the contours of the coastal plain and the present shoreline (Baillie 1984). They are interpreted as being former beach ridges (Bowden 1978).

Late Pleistocene dune sand

Hole 5 was located on a linear sand dune, and the uppermost 2 m of sediment drilled, although strongly podsolised, consisted of very well-sorted medium-grained quartz sand of aeolian origin. The aeolian sands were clearly seen to overlie coarser, less well-sorted sands which contained shell fragments. The dune through which the hole was drilled is part of a field of longitudinal dunes which occurs in the Mussel Roe Bay area (fig. 2), and elsewhere in northeastern Tasmania (Baillie *et al.* 1980; Baillie 1984; Bowden 1978, 1983).

The dunes have an overall WNW–ESE alignment, and, although no absolute age has been determined, are considered to be Last Glacial in age (Bowden 1983; Baillie in McClenaghan *et al.* 1982). Also present in the Mussel Roe Bay area is a series of lunettes (fig. 2) which exhibit strong soil development. The lunettes are developed on sands similar to those encountered in the drill holes and provide an upper age limit for the formation of the older, coarser sands. Lunette formation in south-eastern Australia is usually attributed to the later part of the Last Glacial stage between 10 000 and 26 000 years b.p. (*e.g.* Bowler 1971, 1976).

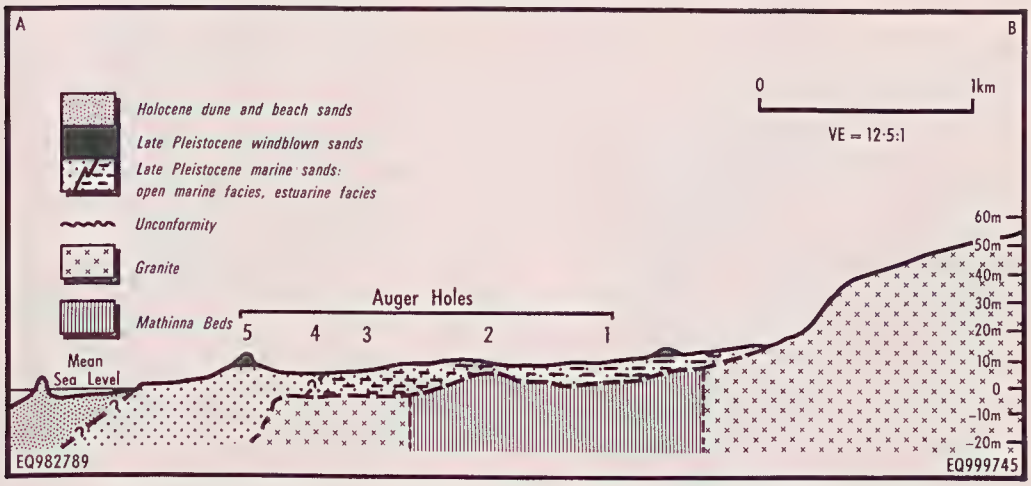

FIG. 3 — Generalised section along Line A–B of figure 2 showing overall stratigraphic relationships as determined by drilling

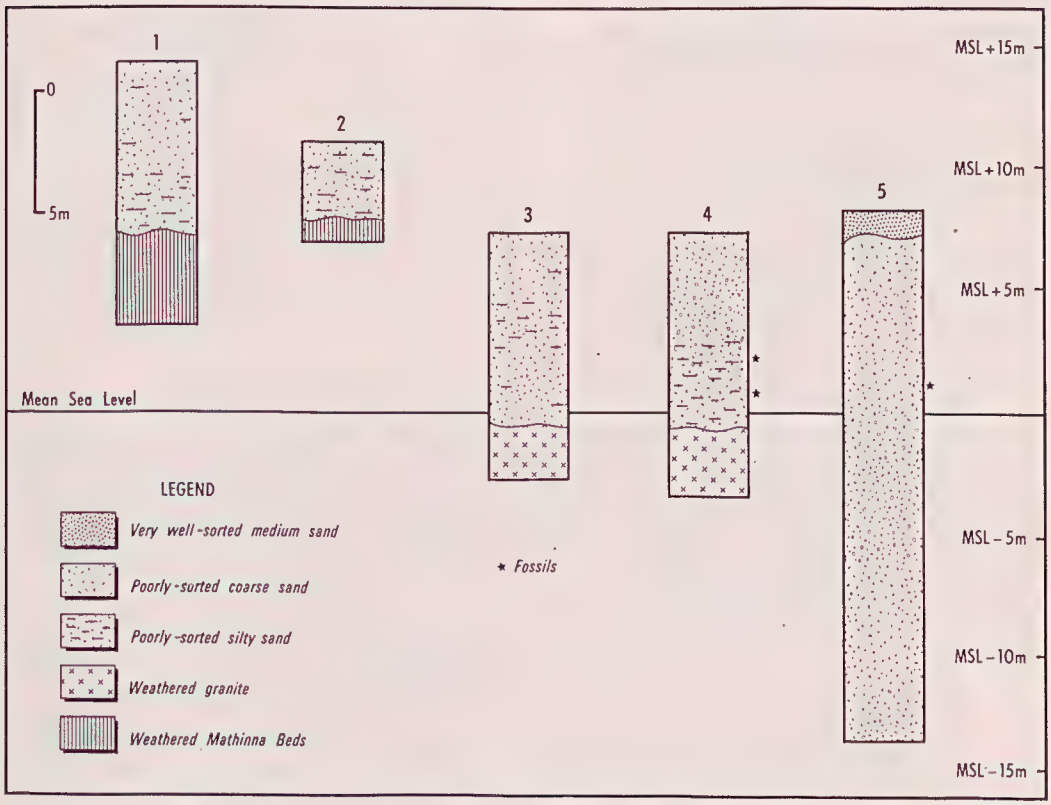

FIG. 4 — Stratigraphy of auger holes drilled at Mussel Roe Bay

TABLE 1

Species	Environment
Austrocochlea constrica zebra (Menke, 1829)	large rock, intertidal
Clanculus dunkeri (Koch, 1843)	large rock, intertidal
Clanculus plebejus (Philippi, 1851)	large rock, intertidal
Gibbula hisseyana (Tenison Woods, 1876)	small rock
Lissotesta micra (Tenison Woods, 1877)	small rock
?Brookula densilaminata (Verco, 1907)	small rock
Pisinna frenchiensis (Gatliff and Gabriel, 1908)	small rock
Assiminea tasmanica (Tenison Woods, 1876)	some freshwater influence
Hydrobia buccinoides (Quoy and Gaimard, 1835)	some freshwater influence
Hydrobia sp.	
Zeacumantus diemenensis (Quoy and Gaimard, 1834)	mud or sand flats
Diala lauta (A. Adams, 1862)	mud or sand flats
Diala pagodula (A. Adams, 1862)	mud or sand flats
Diala translucida (Hedley, 1905)	mud or sand flats
Agatha metcalfei (Pritchard and Gatliff, 1900)	small rock
Chemnitzia mariae (Tenison Woods, 1876)	small rock
Seila albosutura (Tenison Woods, 1876)	small rock
Lepsiella vinosa (Lamarck, 1822)	small rock
Propefusus sp.	large rock
Retusa spp.	small rock
Nassarius pauperatus (Lamarck, 1822)	mud or sand flats
Nassarius pyrrhus (Menke, 1843)	mud or sand flats
Mytilus sp.	rock
Ostrea angasi (Sowerby, 1871)	rocks in sand or mud
Micromytilus crenatuliferus (Tate, 1892)	mud or sand flats
Radiocondyla pectinata Tate and May, 1900	mud or sand flats
Myrtea sp.	mud or sand flats
Wallucina assimilis (Angas, 1867)	mud or sand flats
Arthritica helmsei (Hedley, 1915)	mud or sand flats
Mysella donaciformis (Angas, 1878)	mud or sand flats
Katelysia rhytiphora (Lamy, 1937)	mud or sand flats
Katelysia scalarina (Lamarck, 1818)	mud or sand flats
Anapella cycladea (Lamarck, 1818)	mud or sand flats
Tellina (Macomona) deltoidalis Lamarck, 1818	mud or sand flats
Legrandina bernardi Tate and May, 1902	mud or sand flats

Holocene deposits

Mussel Roe Bay is the estuary of the Great Mussel Roe River and is largely cut off from the sea by a bay-mouth bar which is over 5 km in length. This bay-mouth bar forms the beach of Great Mussel Roe Bay (fig. 2), and is, in part, developed on Late Pleistocene sands (Baillie 1984). The configuration of the bar indicates longshore drift towards the southeast. The entrance to Mussel Roe Bay is about 50 metres wide at high tide.

PLEISTOCENE FAUNAS

The faunas encountered in Hole 4 contained both foraminifera and molluscs. Although stratigraphic relationships have demonstrated that the fossil status of the fauna is unequivocal, all specimens belong to extant species.

Of the foraminifera about 65% are *Ammonia beccarii* (Linne). The remaining 35% consists dominantly of *Elphidium crispum* (Linne), with isolated examples of *E. jenseni* (Cushman) and *E. poeyanum* (d'Orbigny). In the Australian context the foraminifera are typical of the river channel part of an estuarine system where salinity changes regularly (Quilty 1977).

The molluscs (table 1; see later) include 34 species in a good state of preservation. Most species indicate deposition in an estuarine environment of tidal mud or sand flats, but trochids such as *Austrocochlea* and *Clanculus* indicate that some large rocks were also present. Other trochids (*Gibbula* and *Lissotesta*), together with *Pisinna, Seila, Chemnitzia* and *Agatha* may have inhabited smaller boulders. *Assiminea* and *Hybrobia* indicate freshwater influence.

AGE AND ENVIRONMENT

The shell-bearing deposits are older than aeolian sands for which a Late Glacial age is indicated. Because the deposits occur close to, or above present sea level an interglacial age is most probable. The Last Interglacial reached its maximum about 125 000 years b.p., and earlier interglacials occurred at about 230 000 years b.p. and earlier. (Shackleton *et al.* 1984; Shackleton and Opdyke 1973.

Because primary depositional features are preserved at Stumpys Bay it is considered that a Last Interglacial age is likely, as older morphological forms would not have survived the Last Interglacial unless at a higher level. This age is in agreement with the findings of van de Geer *et al.* (1979) who conclude that all Pleistocene marine deposits known from mainland Tasmania are of Last Interglacial age.

The environment of deposition of the sediments drilled is considered to be the same as that currently present in the area. The estuarine sediments encountered in Hole 4 were barred from the open sea by a bay-mouth bar as seen in the coarse sands of Hole 5. The transgressive nature of the system is seen in Hole 4 where the estuarine sediments are overlain by cleaner, coarser sands.

It is noteworthy that all samples were bimodal in character with some 12–30% by weight occurring as grains greater than 0ϕ (very coarse sand, granules, pebbles). This indicates that the local granite was the major sediment source. Granitoids in the area vary from medium-grained (quartz approx. 2 mm diameter) to very coarse-grained (quartz greater than 4 mm diameter). As every sample examined displayed bimodality it is considered that the effect is real, and not an artifact resulting from auger drilling.

CONCLUSIONS

Estuarine and marine sands in the Mussel Roe Bay area were deposited during the Last Interglacial Stage, about 125 000 years b.p. The depositional environment was similar to present, i.e. on estuary barred from the sea by a bay-mouth barrier.

ACKNOWLEGMENTS

Legrandina bernardi was identified by Dr N.H. Ludbrook, Adelaide. The paper was critically read by M.J. Clarke and E. Williams. PWB publishes with permission of the Director of Mines, Hobart.

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A PLIOCENE FORAMINIFERID FAUNA FROM FLINDERS ISLAND, BASS STRAIT

by Patrick G. Quilty

(with one text-figure and one table)

QUILTY, P.G., 1985 (31:vii): A Pliocene foraminiferid fauna from Flinders Island, Bass Strait, *Pap. Proc. R. Soc. Tasm.* 119:89–91. ISSN 0080-4703. Antarctic Division, Department of Science, Kingston, Tasmania.

A foraminiferid fauna from the Cameron Inlet Formation, Flinders Island, Tasmania is probably Late Pliocene in age. The benthic foraminiferid fauna has a strong Kalimnan aspect but the formation is probably a little younger than the stratotype Kalimnan.

Key Words: Foraminifera, Pliocene, Flinders Island.

INTRODUCTION

Sutherland and Kershaw (1971) summarised the Cainozoic geology of Flinders Island, and referred to the Cameron Inlet Formation as having variable lithology (predominantly glauconitic calcareous sand and silt) and seldom exceeding 7.5m in thickness. It covers a considerable area of eastern and southeastern part of the island beneath a veneer of Quaternary sediments. They very effectively reviewed studies prior to that date and presented a comprehensive list of molluscs identified by previous authors, which provided a basis for assigning a Middle-Late Pliocene age to the faunas. In addition there was a reference to four species of foraminiferids identified by A.C. Collins and to an inner continental shelf environment of deposition based on the ratios of planktic to benthic foraminiferids identified by D.J. Taylor.

The present study is based on a sample of the Cameron Inlet Formation collected in 1980 at Warren's Farm, North Patriarch dragline drain (39°58′S:148°07′E; fig. 1) by Dr F.L. Sutherland, Australian Museum, Sydney. The sample supplied consists of a very friable, slightly weathered, very poorly sorted, highly calcareous sandstone with abundant molluscan (particularly bivalve) remains, many unbroken. All aspects are of a very shallow, quiet water environment of deposition, perhaps in a marine lagoon.

Quilty (1972) summarised knowledge of the Tertiary stratigraphy of Tasmania based on foraminiferid studies and recorded no good faunas younger than Early Miocene but later (1985) described a Pliocene fauna dredged from the sea floor off St Helens in northeastern Tasmania

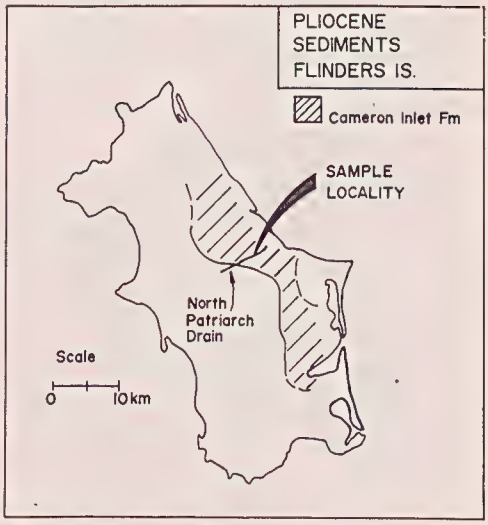

FIG. 1 — Locality Map

FORAMINIFERIDA AND CORRELATION

The benthic fauna (table 1) is very similar to that described by Carter (1964) from the onshore Jemmys Point Formation of the Gippsland Basin. Common important benthic foraminiferids include *Valvulineria kalimnensis, Florilus* (*Nonion* of Carter) *victoriensis, Astrononion tasmaniensis, Elphidium imperatrix.* These perhaps suggest that while age may be similar, environment of deposition controls the very great benthic similarity. The fauna does allow correlation with the Kalimnan of

TABLE 1
FORAMINIFERIDA, CAMERON INLET FORMATION, FLINDERS ISLAND

Benthic Foraminiferids

	%		%
Valvulineria kalimnensis (Parr)	13	*Sigmoidella elegantissima* (Parker & Jones)	1
Lagena spp	9	*Lenticulina* sp.	1
Elphidium pseudonodosum Cushman	7	*Guttulina regina* (Brady, Parker & Jones)	1
Discorbinella bertheloti(d'Orbigny)	7	*Oolina* sp.	1
Fissurina spp	5	*Pileolina* sp.	1
Cibicides thiara Stache	5	*Crespinella* sp.	1
Astrononion tasmaniensis Carter	3	*Elphidium crassatum* Cushman	1
Guttulina communis (d'Orbigny)	3	*E. jenseni* (Cushman)	1
Rosalina mitchelli Carter	3	*Siphotextularia* cf. *concava* (Karrer)	
R. sp.	3	*Quinqueloculina intricata* Terquem	
Anomalinoides sp.	3	*Q. ?venusta* Karrer	
Elphidium imperatrix (Brady)	3	*Q. lamarckiana* d'Orbigny	
E. macellum (Fichtel & Moll)	2	*Guttulina pacifica* (Cushman & Ozawa)	
Notorotalia howchini (Chapman, Parr & Collins)	2	*Polymorphina* sp.	
Quinqueloculina seminulum (Linnaeus)	2	*Bolivina* sp.	
Pyrulina angusta (Egger)	2	*Cancris* sp.	
Pileolina aff. *australensis* (H.A. & E.)	2	*Pileolina wiesneri* (Parr)	
Florilus victoriensis (Cushman)	2	*Discorbinella planoconcavata* (C.P. & C.)	
Elphidium chapmani Cushman	1	*Planulinoides biconcavus* (Jones & Parker)	
Gyroidina neosoldanii Brotzen	1		

Planktic foraminiferids

	%		%
Globigerina bulloides d'Orbigny	38	*G. (Truncorotalia) crassaformis ronda* Blow	3
Turborotalita quinqueloba (Natland)	34	*Globigerina rubescens decoraperta* Takayanagi & Saito	3
Globorotalia (Truncorotalia) crassaformis crassaformis (Galloway & Wissler)	13	*Globorotalia (Truncorotalia) inflata* (d'Orbigny)	2
Neogloboquadrina pachyderma (Ehrenberg)	7	*Globigerina pachyderma* (Ehrenberg) form 1 of Keller 1978	

% indicates percentage of benthic or planktic species respectively

Planktic Percentage 23

Singleton (1941) in the southeastern Australian Tertiary in benthic (and thus dominantly environmental) terms.

While the planktic fauna makes up 23% of the total, diversity is low and many key forms in major zonal schemes (e.g. that of Blow, 1969) are absent. This fauna lacks keeled globorotaliids, sphaeroidinellids, pulleniatinids and *Globigerinoides*. Species present include *Globorotalia inflata, G. crassaformis, Globigerina bulloides* and *G. rubescens decoraperta*. These allow correlation with Blow's N20 or N21, that is mid or Late Pliocene, although for reasons given below, the Late Pliocene age is preferred.

The Kalimnan age determination for the Cameron Inlet Formation based on foraminiferids could be seen as being in conflict with the age based on molluscs which suggest an age slightly younger than Kalimnan (Darragh and Kendrick, 1971) because of the high proportion of living species therein. Darragh and Kendrick suggested a "Middle to Upper Pliocene" age. Darragh (1985) referred the Cameron Inlet Formations mollusc fauna to his Molluscan Assemblage XVII and regarded it as Late Pliocene, noting that no diagnostic foraminiferids have been recovered and that no southeastern Australian stage name is appropriate.

The foraminiferid fauna, as noted above, is one likely to be largely environmentally controlled (as could be expected also of the molluscs) but has a strong Kalimnan aspect. Abele *et al.* in Douglas and Ferguson (1976) took the Kalimnan to correlate approximately with zones N19 or N20 of Blow's (1969) scheme. The correlation suggested above with N20 or N21 is consistent with the mollusc evidence and with the Late Pliocene age determination. It is thus either post Kalimnan or perhaps partly overlapping with the later Kalimnan.

The Gippsland Basin contains in its offshore part the only apparently continuous Pliocene to Recent marine sequence so far encountered in southeastern Australia. Hocking (1972) referred all units of the Pliocene-Recent, although lithologically not sandstone, to the Jemmys Point Formation. Onshore, the section consists of a discontinuous sequence including marine sections such as sandstone of the Jemmys Point Formation, grading upwards into non-marine sediments and including several hiatuses.

Abele in Douglas and Ferguson (1976) recognised only Early (Zanclian) and Late (Piacenzian) in the Pliocene of Victoria. The Kalimnan appears to straddle the boundary between the two stages but its boundaries remain ill defined involving species not identified here. Planktic species recorded here do not allow correlation with the scheme proposed by Abele as *Globorotalia acostaensis* is absent from the Flinders Island section.

ENVIRONMENT OF DEPOSITION

The 23% planktic content suggests inner to middle continental shelf depth of deposition. The absence of *Ammonia beccarii* — whose presence is a feature of the type Kalimnan — is consistent with fully marine conditions.

The groups listed above as absent are all associated with warm water conditions. Their absence is negative evidence consistent with either cool or very shallow water conditions (or both). It is unlikely in the inferred conditions of deposition that the apparent absence is not real. Thus the sample is taken as representing deposition in cool conditions.

An explanation for the apparent cool water aspect of the fauna is that it is younger than the mid — Pliocene fauna recorded in the accompanying paper (Quilty 1985). That fauna probably represents the last warm water phase before the initiation of what became the Pleistocene glaciation.

COMPARISON WITH OTHER TASMANIAN SECTIONS

Quilty (1985) has recorded a warmer water Pliocene fauna from the east coast, offshore from St Helens; the two samples representing Tasmania's only known Pliocene. The other fauna, in addition to this, suggests that Tasmania has a patchy Neogene sediment record but one which includes evidence of a change from a warm mid-Pliocene to cool water Late Pliocene in eastern Tasmania.

SAMPLES AND ACKNOWLEDGEMENTS

A representative sample of the foraminiferids is held in the collection of the University of Tasmania, Geology Department as specimen number UTGD 122867. The author is indebted to Dr F.L. Sutherland Australian Museum Sydney, for providing the sample and to Dr T. Darragh, National Museum of Victoria, Melbourne, for helpful discussions.

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(accepted May 1, 1985)

MIOCENE AND PLIOCENE SEDIMENTS DREDGED FROM THE SEA FLOOR OFF ST HELENS, NORTHEASTERN TASMANIA

by Patrick G. Quilty

(with two text-figures, two tables and two plates)

QUILTY, P.G., 1985 (31:vii): Miocene and Pliocene sediments dredged from the sea floor off St Helens, northeastern Tasmania. *Pap. Proc. R. Soc. Tasm.*, 119:93–101, pls 2. ISSN 0080–4703. Antarctic Division, Department of Science, Kingston, Tasmania.

Calcarenites dredged from 807 and 960m, 50km southeast of St Helens, Tasmania, have yielded Early Miocene and mid-Pliocene foraminiferid faunas. The Miocene fauna is a deeper water continental shelf type of the same age (N4/5) as other sediments well known from the northern coast of Tasmania. It contains a higher percentage of planktic forms than known in coeval sediments elsewhere in Tasmania. The mid-Pliocene (approximately N20) including a significant planktic component, is the first such fauna documented from Tasmania.
Key Words: Miocene, Pliocene, foraminifera, Tasmania.

INTRODUCTION

Very little is known of the Cretaceous-Cainozoic geological history of southeastern Australia marginal to the Tasman Sea apart from the results of the studies of onshore sections by Carter (1964) and the extensive summary by Abele *et al.* in Douglas and Ferguson (1976) of the Gippsland Basin Tertiary. In eastern Tasmania, the only Tertiary foraminiferids studied are those from Great Mussel Roe Bay and the islands of the Furneaux Group by Quilty (1972) who recognised only Early Miocene (possibly latest Oligocene in Great Mussel Roe Bay).

Thus there is a marked gap in knowledge concerning development of oceanic circulation patterns, water temperature changes in the oceans and results of onshore drainage since sometime in the Cretaceous, although generalised evolution of these aspects has been addressed by Deighton *et al.* (1976), Edwards (1975) and Kennett *et al.* (1975).

Two new sample locations have been identified by fortuitous recovery of sedimentary rocks from the sea floor during trawling operations by the Tasmanian Fisheries Development Authority, some 30km offshore, approximately 50km southeast of St Helens (fig 1) and 130km south-southeast of the closest known marine Tertiary samples from submarine outcrops in Great Mussel Roe Bay.

Australian Tertiary Stage terminology, as summarised by Abele in Douglas and Ferguson (1976), includes in the Pliocene the early part of the Cheltenhamian, the Kalimnan and the Werrikooian. Most of the Pliocene so far studied is from shallow water sections containing characteristic benthic forms. The new Tasmanian sample is a deeper water sediment, lacking the characteristic benthic foraminiferids, but including a planktic fauna probably representing the total diversity living in the area at an instant in the Pliocene. Thus Australian stage terminology is not readily applicable to the Pliocene recorded here.

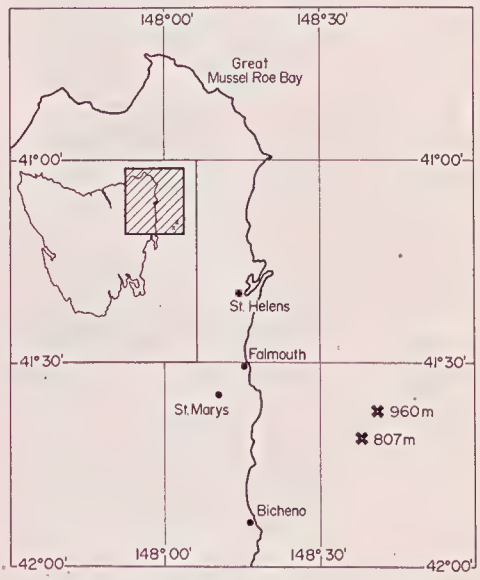

FIG. 1 — Location of samples

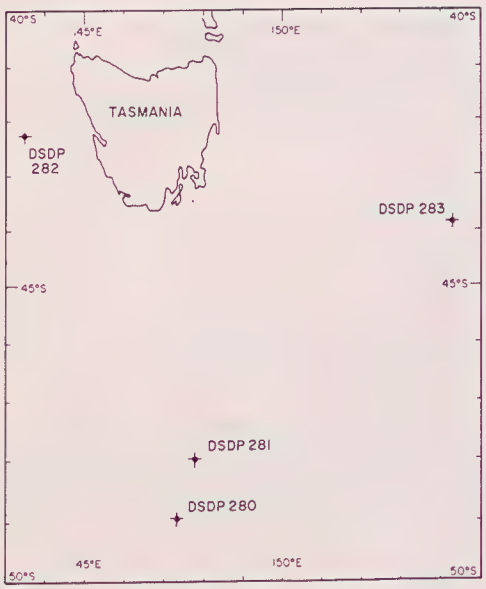

FIG. 2 — Locality map showing Deep Sea Drilling Project sites

Contemporaneous faunas of New Zealand are well known through such works as Hornibrook (1961) and Jenkins (1971).

Five Deep Sea Drilling Project sites can be regarded as close to Tasmania. They are site 280–283 (fig. 2) and 284 some 300km west of the northern tip of the South Island of New Zealand. Early Miocene sections, equivalent to that recorded are found in the following drill-holes: Site 281, 93–119m (lower part); Site 282, 9–55m (lower part); Site 283, 10–19m (?). The only Pliocene sections equivalent to that recorded here, are found at Site 283, somewhere in the interval 0–0.5m and particularly in site 284 (approximately 110–140m).

Specimens of the rocks and figured specimens are housed at the Geology Department, University of Tasmania and accession numbers are listed in the plate explanations.

NEW MATERIAL

The samples come from the following locations:-

A 41° 40.8'S : 148° 38.6'E water depth 807m
B 41° 37'S : 148° 42'E water depth 960m

They are thus from the present day continental slope and are taken to represent outcrops of Tertiary sediment on the seafloor.

Two lithologies and two environments are represented. It is unknown which rock type comes from which locality. The lithologies are: 1. Pale grey, fine-grained, poorly-sorted, somewhat consolidated bryozoal calcarenite; 2. Yellowish, ferruginous, medium to coarse-grained, well-sorted, friable bryozoal calcarenite.

The rocks have a very different appearance, suggesting very different marine environments of deposition and this is supported by study of the foraminiferids which shows that the rocks formed at quite different times and environments.

RESULTS

Pale grey, fine-grained calcarenite (sample 1 above)

Age

Planktic foraminiferid basis.

The sample contains a very numerous planktic component but diversity is low and the fauna is predominantly of species of *Globigerina* (table 1). Jenkins (1971) studied the distribution of planktic foraminiferids from New Zealand and is thus the only author who has attempted a comprehensive review of the planktic foraminiferid faunas from sections of rocks of comparable age in a nearby locality.

The main diagnostic forms present are *Globoquadrina dehiscens dehiscens* (Chapman, Parr and Collins), *Globigerina woodi woodi* Jenkins *G. w. connecta* Jenkins, G. *labiacrassata* Jenkins, *Globigerinoides quadrilobatus immaturus* LeRoy and *Globorotalia (Turborotalia) nana* Bolli. It has been difficult to identify the specimens uniquely in every case even though preservation is good, and a large part of the fauna has been assigned to intermediate forms in the *G. w. woodi–G. w. connecta* plexus. The identification of G. *labiacrassata* seems a little anomalous, particularly as it makes up a significant part of the fauna. It may be that other authors would include all such specimens in *G. woodi*. However the specimens recovered here seem typical morphotypes and as noted by Kennett and Srinivasan (1984), there is a strong phylogenetic link between the species. A degree of subjectivity is involved in their differentiation.

The age of the fauna is taken on planktic forms alone, to be Early Miocene, *Globigerina w. woodi* or *G. w. connecta* Zones of Jenkins (1971) or approximately N4 or N5 (*Globigerinoides quadrilobatus primordius/ Globorotalia kugleri* Zone or *Globoquadrina dehiscens praedehiscens–G. dehiscens dehiscens* Zone) of the scheme proposed by

TABLE 1
SPECIES RECORDED FROM EARLY MIOCENE SEDIMENT

Benthic Foraminiferids

	%	Rank
Cibicidoides perforatus (Karrer)	27	1
Karreria maoria (Finlay)	14	2
Cibicides thiara Stache	10	3
Gaudryina convexa (Karrer)	8	4
Lenticulina sp.	5	5
Eponides repandus (Fichtel & Moll)	4	6
Globocassidulina subglobosa (Brady)	3.6	7
Gypsina globulus (Reuss)	2.8	8
Heronallenia lingulata (Burrows & Holland)	2.8	8
Siphonina australis Cushman	2.8	8
Discorbis balcombensis Chapman, Parr & Collins	2.4	11
Notorotalia clathrata (Brady)	2.2	12
Planulinoides biconcavus (Jones & Parker)	2.2	12
Ehrenbergina serrata Reuss	1.5	14
Sphaeroidina bulloides d'Orbigny	1.5	14
Notorotalia howchini Chapman, Parr & Collins	1.4	15
Discorbinella sp.	1.1	16
Glabratella globigeriniformis (Heron-Allen & Earland)	1.1	16
Rosalina sp.	1.1	16
Guttulina sp.	1.0	19
Anomalinoides nonionoides (Parr)	.7	20
Siphotextularia cf. *bolivina* Hornibrook	.4	21
Sigmoidella elegantissima (Parker & Jones)	.4	21
Mississippina concentrica (Parker & Jones)	.3	23
Fissurina spp.	.3	23
Lagena spp.	.3	23
Reussella simplex (Cushman)	.3	23
Planodiscorbis irregularis Carter	.3	23
Guttulina communis (d'Orbigny)	.1	28
Bolivina victoriana Cushman	.1	28
Spirillina sp.	.1	28
Elphidium chapmani Cushman	.1	28
Anomalinoides macraglabrus (Finlay)	.1	28
Gyroidina neosoldanii Brotzen	.1	28
Sigmomorphina wynyardensis Parr & Collins	0	34
Astrononion centroplax Carter	0	34
Operculina victoriensis Chapman & Parr	0	34
Gypsina sp.	0	34

Planktic Foraminiferids

	%	Rank
Globigerina praebulloides group	31	1
Globigerinita glutinata (Egger)	25	2
Globigerina brazieri Jenkins	16	3
Globoquadrina dehiscens dehiscens (Chapman, Parr & Collins)	14	4
Globigerina labiacrassata Jenkins	6	5
G. woodi woodi Jenkins	3.5	6
Globorotalia nana Bolli	2.5	7
G. zealandica Hornibrook	1.7	8
Globigerina woodi connecta Jenkins	1.3	9
G. bulloides bulloides d'Orbigny	.1	10
G. rubescens decoraperta Takayanagi & Saito	.1	10
Globigerinoides quadrilobatus immaturus Leroy	.1	10

Blow (1969). Therefore the samples are comparable in age with much of the Tertiary along Tasmania's northern and northwestern coast documented by Quilty (1972), but the deeper water aspect shows that the planktic content recorded here represents a greater diversity whereas the earlier studies were on shallower faunas probably of reduced diversity.

Benthic foraminiferid basis.

Carter in particular has contributed a great deal to the knowledge of the stratigraphic distribution of southeastern Australian benthic foraminiferids (Carter 1958, 1964) and this has been extended by Quilty (1974, 1977, 1982) to include the Tasmanian species. Key species in Carter's Schemes to be recovered here are *Discorbis balcombensis* Chapman, Parr and Collins, *Notorotalia howchini* (Chapman, Parr and Collins), *Astrononion centroplax* Carter and *Operculina victoriensis* Chapman and Parr, consistent with assignment to Carter's (1958) Faunal Units 6–8, and also consistent with, but not as precise as, the Early Miocene age identified above on the basis of planktics.

TABLE 2
SPECIES RECORDED FROM PLIOCENE SEDIMENT

Benthic Foraminiferids

	%	Rank.
Cibicidoides perforatus (Karrer)	25.5	1
Elphidium crispum (Linnaeus)	9.1	2
Globocassidulina subglobosa (Brady)	6.6	3
Cibicides cicatricosus (Schwager)	6.0	4
Euuvigerina compacta Collins	4.9	5
Cassidulina neocarinata Thalmann	3.3	6
Elphidium imperatrix (Brady)	2.7	7
Textularia sagittula Defrance	2.5	8
Gaudryina convexa (Karrer)	2.3	9
Ehrenbergina serrata Reuss	2.2	10
Lagena spp.	2.1	11
Cibicidoides mediocris (Finlay)	1.9	12
Elphidium verriculatum (Brady)	1.9	12
Pileolina australensis (Heron-Allen & Earland)	1.8	14
Anomalinoides cf. *macraglabrus* (Finlay)	1.8	14
Quinqueloculina lamarckiana d'Orbigny	1.6	16
Lenticulina sp.	1.5	17
Buliminella elegantissima (d'Orbigny)	1.4	18
Miliolinella subrotunda (Montagu)	1.4	18
Cibicides cf. *lobatulus* (Walker & Jacob)	1.3	20
Guttulina communis (d'Orbigny)	1.2	21
Fissurina spp.	1.1	22
Trifarina bradyi Cushman	1.0	23
Planulina ariminensis d'Orbigny	.9	24
Osangularia sp.	.8	25
Textularia sp.	.7	26
Bolivina alata (Seguenza)	.7	26
Discorbinella subbertheloti (Cushman)	.7	26
Pyrgo vespertilio (Schlumberger)	.6	29
Quinqueloculina granulosa Natland	.6	29
Q. laevigata d'Orbigny	.6	29
Cornuspira incerta (d'Orbigny)	.5	32
Quinqueloculina oblonga (Montagu)	.5	32
Planodiscorbis rarescens (Brady)	.5	32
Pullenia bulloides d'Orbigny	.5	32
Discorbis procera (Brady)	.5	32
Pileolina sp.	.5	32
Triloculina trigonula (Lamarck)	.4	38
Rectobolivina columellaris (Brady)	.4	38
Cibicidoides pseudoungerianus (Cushman)	.4	38
Textularia vertebralis Cushman	.3	41
Dorothia parri Cushman	.3	41
Martinottiella sp.	.3	41
Epistomina elegans (d'Orbigny)	.3	41
Unidentified miliolid	.3	41
Spirillina vivipara Ehrenberg	.3	41
Gavelinopsis lobatulus (Parr)	.3	41
Glabratella sp.	.3	41
Astrononion sp.	.3	41
Quinqueloculina angularis d'Orbigny	.2	50
Bulimina fijiensis (Cushman)	.2	50
Spirillina decorata Brady	.2	50
S. sp.	.2	50
Pileolina opercularis (d'Orbigny)	.2	50
Planulinoides biconcavus (Jones & Parker)	.2	50
Planopulvinulina dispansa (Brady)	.2	50
Cymbaloporetta sp.	.2	50
Eponides repandus (Fichtel & Moll)	.2	50
Calcarina calcar d'Orbigny	.2	50
Pullenia subcarinata (d'Orbigny)	.2	50
Gyroidina broeckhiana (Karrer)	.2	50
Pyrgo depressa (d'Orbigny)	.1	62
Marginulina sp.	0	63
Pseudopolymorphina sp.	0	63

Planktic Foraminiferids

	%	Rank.
Globorotalia inflata (d'Orbigny)	37	1
small globigerinids	24	2
Globigerina bulloides bulloides d'Orbigny	11	3
Globorotalia acostaensis acostaensis Blow	10	4
G. scitula scitula (Brady)	5	5
Globigerina rubescens decoraperta Takayanagi & Saito	4	6
Globigerinita sp.	3.2	7
G. quinqueloba (Natland)	1.4	8
G. sp. indet.	1.2	9
Globorotalia obesa Bolli	1.2	9
G. crassula crassula Cushman & Stewart	.6	11
Orbulina universa d'Orbigny	.5	12
Globigerina falconensis Blow	.4	13
Globorotalia crassaformis (Galloway & Wissler)	.3	14
Globigerinita incrusta Akers	.2	15
Globorotalia conomiozea mons Hornibrook	.2	15
Hastigerina pelagica d'Orbigny	.1	15
Globorotalia hirsuta praehirsuta Blow	.1	17

Environment of Deposition

Depth

Planktic foraminiferids comprise 62% of the total fauna, suggesting a middle to outer continental shelf regime. The absence of large shallow water benthics (such as *Amphistegina, Planorbulinella* spp., *Sherbornina*) all are inconsistent with an inner shelf origin. The high diversity (19 species making up 95% of the benthic fauna) and moderate dominance (percentage of the fauna consisting of the dominant species — 27) are consistent with the planktic indications. The low proportion of buliminids, presence of very rare shallow species (e.g. *Operculina victoriensis*) and presence of large numbers of an attached form such as *Karreria maoria* (Finlay) would suggest a shallower origin than outer shelf. Perhaps overall, the indicators suggest a middle shelf origin, say approximately 100–150m.

There are about 265 foraminiferids per gram of sediment.

Temperature

The presence of *Operculina victoriensis* and *Gypsina globulus* suggests that the benthic forms occupied warm temperate waters or warmer. This is in contrast with the planktic indicators.

There are no keeled globorotalids, consistent with the results elsewhere around Tasmania for faunas of this age (Quilty 1972). The total planktic fauna consists of nine species and subspecies and thus although numerically large, has a diversity similar to that in modern cool temperate faunas. Bandy (1964) would suggest that the presence of non-keeled globorotalids would occur in water temperatures of 9–17° C. The very low numbers would indicate the lower part of that temperature range.

Other aspects of the enviornment.

All other indications are that normal open ocean conditions applied.

Yellowish, coarse-grained calcarenite (Sample 2 above)

Age

Planktic foraminiferid basis.

Jenkins (1971), Kennett and Vella (1975) and Srinivasan and Kennett (1981a, b) have provided a basis for comparison of the faunas from the new samples with deeper water, more complete sections. In addition the monumental work by Blow (1969) has provided a useful foundation.

This sample contains abundant planktic foraminiferids, dominated by *Globorotalia inflata*. (Also present are *G. acostaensis acostaensis, G. conomiozea mons, G. crassaformis, G. hirsuta praehirsuta, Globigerina rubescens decoraperta* and many other species (see table 2) not diagnostic of age at this level. All these determinations (other than *Globorotalia conomiozea mons*) are consistent with the Late Pliocene faunas recorded by Srinivasan and Kennett from DSDP Site 281. Srinivasan and Kennett (1981b, fig. 8) summarised all the available data and in that scheme, the present samples clearly correlate best with the mid Pliocene, *Globorotalia crassaformis* Zone, approximately N20. *G. r. decoraperta* is transitional to *G. r. rubescens* perhaps also consistent with an N20 age.

In the scheme proposed by Hornibrook (1982) for DSDP Site 284, the correlation would suggest an older age (*G. puncticulata* or *G. margaritae* Zones) if the apparently anomalous early appearance of *G. inflata* is ignored. If *G. c. mons* is ignored, all schemes become compatible and the age can be taken as mid-Pliocene. Blow's (1969) and Jenkins' (1971) works do not allow an age determination more precise than "Pliocene". This appears to be the first foraminiferid-based Pliocene age documented from Tasmania.

As important in this context as the species present, are those not known in the sample. Despite detailed searching, there is no evidence of *Globorotalia truncatulinoides* d'Orbigny or any sphaeroidinellids or pulleniatinids. *Globigerinoides* also is absent.

Benthic foraminiferid basis.

Much of the development of Australian Stage terminology is based on the study of molluscs and benthic foraminiferids. Molluscs are common in this sediment but have not been studied. Benthic foraminiferids are abundant but seem to be of a deeper water facies than usually encountered in the Australian Pliocene known so far, and thus age diagnostic forms are absent.

Environment of Deposition

Depth

The fauna contains 53% planktic forms and thus can be regarded as a middle continental shelf fauna. This figure probably is lower than it should be because the sediment shows considerable evidence of winnowing. Dominance is 25% and diversity about 40, roughly consistent with middle to inner shelf values as developed in the Gulf of Mexico (Walton 1964). The higher content of buliminacean species suggests water a little deeper than for the Early Miocene sample. There are no shallow water indicators. The sediment probably accumulated near or a little over the continental shelf edge, perhaps in a situation and under conditions similar to those where the samples were taken.

Temperature

Water temperature was probably higher than in the Early Miocene of the vicinity. Only the *Lepidocyclina* limestone of northwestern Tasmania (Quilty 1972) would represent considerably warmer Tertiary conditions in Tasmania. The planktic fauna includes keeled *Globorotalia* spp such as *G. conomiozea mons, G. crassula crassula* and *G. hirsuta praehirsuta*, although all are uncommon suggesting that waters may have been cool to warm temperate. As noted earlier other significant warm water groups are absent. Very warm water indices are absent.

Deposition of this mid-Pliocene sediment probably coincided approximately with the Kalimnan of southeastern Australia (approximately N19–early N20; Abele *et al.* in Douglas and Ferguson 1976), although of a much deeper water deposition than the stratotype Kalimnan. There is no benthic basis for correlation between the two sections. As the stratotype Kalimnan probably represents sedimentation at a sea-level high coinciding with the last relatively warm-water period, and immediately prior to a major fall in sea level, this mid-Pliocene sediment is likely to be of a (relatively) warmer-water aspect than any forming in this location since.

According to Shackleton and Kennett (1975) the Late Pliocene was an interval of notably depressed surface water temperatures coinciding with a sea-level low of the order of 50m below present level following a mid-Pliocene high stand probably also coinciding with the last warm water episode before the onset of Pleistocene glaciation. Shackleton and Kennett performed their analyses from DSDP sites on the Pacific plate but no analyses of any significance are available from closer localities particularly from the Indian - Australian plate. Between the Early Miocene and Late Pliocene (some 18–19 million years), Australia had moved north some 1200km, consistent in a general way with increasing sea water temperature.

CONCLUSIONS

Early Miocene and mid-Pliocene marine sediments have been identified from new localities. The Early Miocene sediments are an extension of sedimentary sequences well known from elsewhere around northern Tasmania but mid-Pliocene sediments are not known elsewhere in Tasmania and the environment of deposition has not been recorded in southeastern Australia before.

ACKNOWLEDGEMENTS

My main debt is to Mr Robert Green who had the presence of mind to retain the samples fortuitously dredged. Lesley Manson and Maree Pedder typed the manuscript and Bruce Hill drafted the figures. Gerry Nash was responsible for the electron microscope photography.

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(accepted May 1, 1985)

PLATE 1
MIOCENE PLANKTIC FORAMINIFERIDS

FIG. 1,8 — *Globigerina brazieri* Jenkins; 1. ventral view, x 85. UTGD 122680; 8. dorsal, x 85. UTGD 122680.

FIG. 2,3 — *G. woodi connecta* Jenkins; 2. ventral x 210; 3. dorsal, x 160. UTGD 122681.

FIG. 4 — *G. labiacrassata* Jenkins; 2. ventral x 210; 3. dorsal, x 160. UTGD 122681.

FIG. 5,6 — *G. woodi woodi* Jenkins; 5. ventral, x 85; 6. dorsal, x 100. UTGD 122683.

FIG. 7 — *G. rubescens decoraperta* (Takayanagi and Saito); oblique ventral view, x 110. UTGD 122684.

FIG. 9 — *Globigerinoides quadrilobatus immaturus* LeRoy; dorsal view, x 100. UTGD 122685.

FIG. 10 — *Globigerinita glutinata* (Egger); ventral view, x 150. UTGD 122686.

FIG. 11–13 — *Globoquadrina dehiscens dehiscens* (Chapman, Parr and Collins); 11. ventral x 85; 12. detail of aperture, x 350; 13. dorsal x 105. UTGD 122687.

FIG. 14, 15 — *Globorotalia zealandica* Hornibrook; 14. ventral, x 195; 15. dorsal, x 170. UTGD 122688.

PLATE 2
PLIOCENE PLANKTIC FORAMINIFERIDS

FIG. 1 — *Globorotalia (Truncorotalia) acostaensis acostaensis* Blow; ventral view, x 130. UTGD 122689.

FIG. 2 — *Globigerina falconensis* Blow; ventral view, x 150. UTGD 122690.

FIG. 3 — *Globigerinita incrusta* Akers; ventral view, x 195. UTGD 122691.

FIG. 4 — *Turborotalita quinqueloba* (Natland); ventral view, x 170. UTGD 122692.

FIG. 5,6 — *Globorotalia (Hirsutella) scitula scitula* (Brady); 5. ventral, x 115; 6. dorsal, x 150. UTGD 122693.

FIG. 7,8 — *G. (Truncorotalia) inflata* (d'Orbigny); 7. ventral, x 90; 8. dorsal, x 80. UTGD 122694.

FIG. 9,10 — *G. (Truncorotalia) crassaformis* (Galloway & Wissler); 9. ventral, x 85; 10. dorsal, x 100. UTGD 122695.

FIG. 11,12 — *G. (Hirsutella) hirsuta praehirsuta* Blow, 11. ventral, x 50; 12. dorsal, x 65. UTGD 122696.

FIG. 13,14 — *G. (Truncorotalia) conomiozea mons* Hornibrook; 13. dorsal, x 140; 14. apertural, x 130. UTGD 122697.

FIG. 15–16 — *G. (Truncorotalia) c. crassula* Cushman and Stewart; 15. ventral, x 135; 16. dorsal, x 145. UTGD 122698.

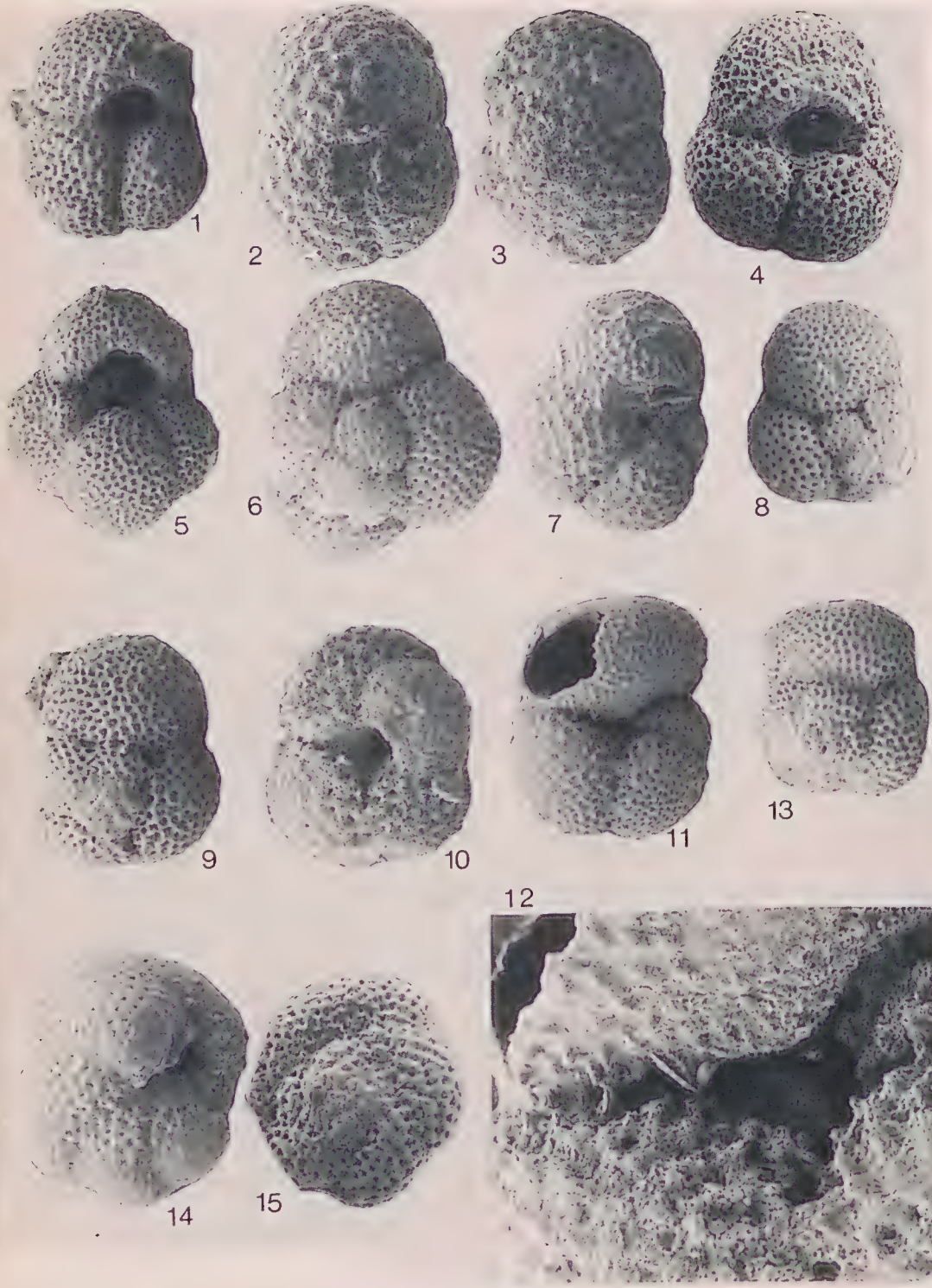

PLATE I

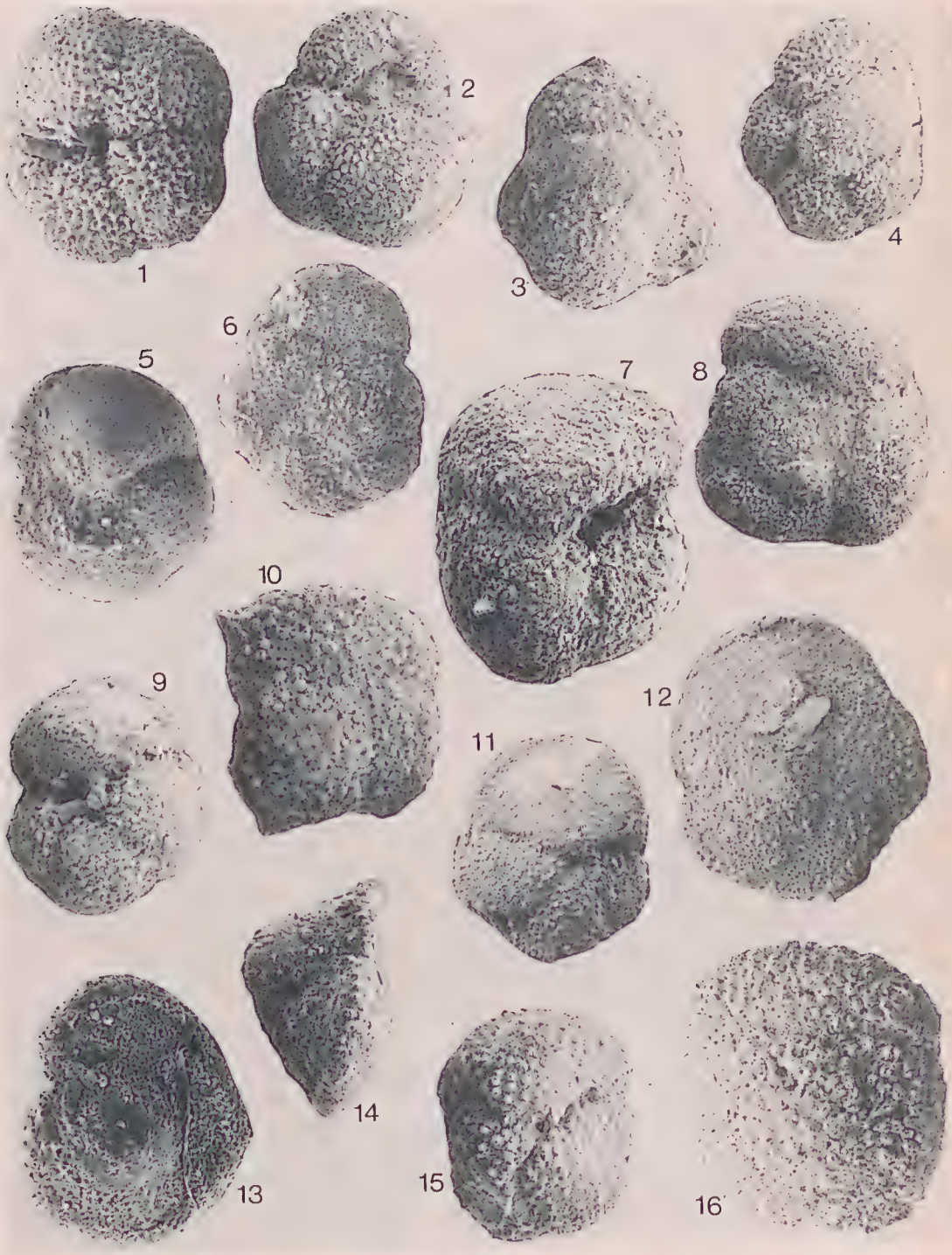

PLATE 2

LOCALISED DECLINES IN COLONIES OF THE SHORT-TAILED SHEARWATER: AN EXPLANATION

by F.I. Norman

(with two text-figures)

NORMAN, F.I., 1985 (31:vii): Localised declines in colonies of the short-tailed shearwater: an explanation. *Pap. Proc. R. Soc. Tasm.* 119:103–107. ISSN 0080–4703. Arthur Rylah Institute for Environmental Research, Fisheries & Wildlife Division, 123 Brown St, Heidelberg, Victoria, Australia 3084.

Historical declines in local populations of the short-tailed shearwater *Puffinus tenuirostris* in the Furneaux Group are reviewed; particular attention is paid to information collected on Big Green Island, off Whitemark, Flinders Island. Disease, predators, and introduced stock are dismissed as causative agents in reported declines of colonies, as is changing vegetation. It is proposed that over-harvesting, initially of all stages and later of young, provides an explanation of such reductions, one which is demonstrated using a simple, deterministic model.
Key Words: Shearwater, decline, Furneaux Group.

INTRODUCTION

Early visitors to the Bass Strait region were impressed by the large number of short-tailed shearwaters or mutton-bird *Puffinus tenuirostris* which they encountered (e.g. Flinders 1814, Davies 1846, Gabriel 1912). However, decreases in areas occupied by breeding colonies on some islands were reported by later authors and various causative agents proposed. The evidence for a decline on one such island is examined in this note and an explanation proposed for the changed nature of the colonies' distribution on the island, and elsewhere.

Big Green Island, Furneaux Group, Tasmania has been described in some detail elsewhere (Norman 1966, 1970a). The island has a long history (since about 1830) of intensive sheep-grazing, with numbers occasionally exceeding 1000. This stocking rate averages about 8 sheep/ha over the island, but is effectively greater when allowance is made for the unvegetated areas of granite which extend over about 50% of the island. During occupancy of the island, rabbits *Oryctolagus cuniculus* were introduced and eliminated, and the vegetation has been changed from a variously reported complex of grasses, thistles and nettles, mallows and saltbush to one typically of a coastal tussock belt (*Stipa teretifolia* and *Poa poiformis*) backed by a predominantly exotic grassland (including *Holcus lanatus, Hordeum leporinum Bromus* spp., and *Trifolium* spp.) maintained by sheep. When Davies (1846) visited Green Island he considered that it was all burrowed, Thomas (1861) found guano in soil samples taken at the northern end, and Backhouse and Tylor (1862) reported a dense colony on the island's southern end. Contemporary newspapers (e.g. *Launceston Examiner* 26 May 1883) mentioned that colonies occupied much of the island. However, by 1893 "the place was a sheep farm, and real mutton was growing where thousands of Mutton Birds used annually to flourish" (Campbell 1900). Montgomery (1891, 1900) also noted with concern the decline in numbers and predicted disappearance of the industrial harvest, although at about the same time (Montgomery, 1898) he had considered it adequately protected. Lord (1908) reported that colonies on the island had decreased to the point that there was only one remaining.

Such historical accounts clearly indicate that shearwater colonies were considered to have occupied much of Big Green Island in the past. To substantiate such statements, and to determine approximate earlier distributions 22 transects were established in 1965 and 1966, across parts of the island not now burrowed by breeding shearwaters, and 270 holes (depths varied according to substrate) dug at intervals. The presence of shearwater bones in 94 of the sample holes was taken as evidence that nesting previously took place in those areas. Comparison of transect information and current (i.e. 1965–1968) colony distribution (fig. 1) indicates that breeding colonies were formerly more extensive, particularly along the eastern slopes of the island. Surface and sub-surface bedrock would have influenced the extent of local burrowing, as it does still.

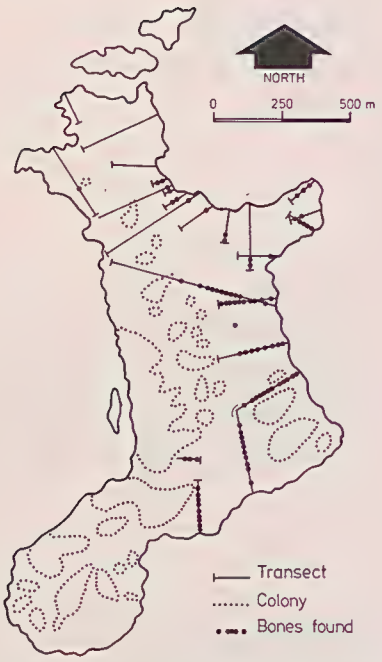

FIG 1 — Distribution of colonies of the short-tailed shearwater on Big Green Island, 1965–1968; the location of earlier colonies as evidenced by bones.

CAUSES OF DECLINE

What then caused the decline of breeding shearwaters on Big Green Island, and perhaps those reported (Montgomery, 1891, Lord 1908, Baker 1909) elsewhere in the Furneaux Group? Diseases, such as 'limy-bird' or ornithosis, or other, do not appear to have been extensively reported and are certainly not now of major, or even continuing, importance. Starvation may affect birds returning to breeding grounds in some years, occasionally in large numbers, and since breeding birds are involved there may be temporary but localised effects, as there would if food was restricted during the breeding season itself. Local breeding success may be reduced substantially in some years following heavy rains (see Serventy 1961, 1967, 1974, Serventy *et al.* 1971 for further details). Potential native mammalian predators, such as the larger dasyurids, have not been recorded from Green Island or from other small islands in the Furneaux Group (Hope 1973), and snakes (tiger snake *Notechis scutatus* or copperhead *Austrelaps superba*), which might take eggs or small young shearwaters (Serventy *et al.* 1971), were early removed (Brownrigg 1872). Avian predators such as the Pacific gull *Larus pacificus* are of little consequence to local populations (Norman 1970b), there are no records of feral cats on the island, and the introduced black rat *Rattus rattus* is not considered to play a role in reducing bird numbers at any stage (Norman 1970c).

Earlier commentators (Thomas 1861, Campbell 1900, Lord 1908, Littler 1910) imputed or stated that sheep were responsible, in part or entirely, for the destruction of the island's colonies. Serventy *et al.* (1971) considered that stock trampled and consolidated ground, thus reducing burrow concentration. However, Norman (1970a) found that sheep did not prevent utilisation of existing colonies on Big Green Island, nor did they decrease breeding success, and artificial burrows were not in demand. Burrow collapses were attributable, during the breeding season, to the birds themselves and occurred in the absence of sheep, as indeed they do elsewhere (Harris & Norman 1981). Long term maintenance of burrows may be related to the type of root system of the covering vegetation. On Green Island, eroding areas of burrows associated with unstable vegetation have not developed, presumably because of the close, dense cover provided by the shallow-rooted, predominantly introduced plant species. The exotic grassland, maintained by grazing sheep (and by infrequent supplementary sowing) did not prevent expansion of breeding colonies. Indeed, on Green Island as in other colonies the shearwater was successfully using areas dominated by exotic vegetation (Harris & Norman 1981, Norman 1970a). Such factors are not therefore considered to have materially affected the size of the breeding population of shearwaters on Big Green Island.

Cott (1953) and others have implicated overharvesting in the decline of the mutton-bird and, despite the views of Serventy *et al.* (1971) that the taking of birds and their eggs were of little consequence, it is appropriate to review some historical aspects of the industry, before examining the direct effects of harvesting.

When Davies (1846) discussed Big Green Island and its shearwaters, he noted that aboriginals were taking large numbers of eggs from it, quite apart from the young harvested later in the 'birding' season. Extrapolation from the details provided by Davies may suggest that over 70,000 eggs were taken but such collections would have been impossible in the mid-1960s when the island's population was estimated at about 10,000 (Norman 1970b). Nevertheless, some 300,000 eggs were removed from nearby Chappell Island in 1864 when the market was "chiefly confined to eggs, fat, oil and feathers (and) comparatively few birds being salted by market" (Lord 1908). Even in 1908 Lord considered that over 1,000,000 birds had been

taken from the Furneaux Group. He noted that eggs and adults were still being taken, estimated recent minimum annual harvests, and felt that "it would be remarkable if the supply did not eventually run out". On Preservation Island harvests were similarly large. Thus Backhouse and Tylor (1862) stated that 2–3 tons were being collected annually, and Elwes (1859) had earlier thought that about 56,000 birds were required to produce a ton of feathers. On Big Green Island itself a birder was taking 15–20,000 shearwaters annually in the late 1870s but apparently found it difficult to get 450 birds in 1907 (Lord 1908). In about 1892 some 2,500 young birds were being taken daily, "for several weeks", to be boiled down for fat production (Legge 1893). There is therefore every reason to assume that on an inhabited island, such as Big Green Island, exploitation rates were high and resembled those pertaining in neighbouring, seasonally-birded colonies.

EXPLOITATION MODELS

Exploitation of a theoretical shearwater population may be examined using data provided by Serventy (1967, 1974), Norman (1970a) and Serventy and Curry (1984), together with information from related species. Such a population may be generated and subjected to varying conditions. Here, a hypothetical population is investigated using a deterministic model in which the following assumptions apply:

i) the population starts with 200 breeding adults aged 6, a foundation group which settled an otherwise unoccupied nesting area;

ii) birds first breed at 6 years of age. Serventy (1967) gave a mean figure of 5.9 years for both sexes and Serventy and Curry (1984) note that some breeding started at 5 years for both males and females and ranged to over 10 years;

iii) pre-breeding birds have an average annual mortality of 15.5%. This approximates the data of Serventy (1967, 1974), who indicated 63% for the 0–3 year group, and 56% for the 3–5 year olds. Serventy and Curry (1984) found that 35% of returning young went on to breed in the natal colony, and some 42% of those fledging were recaptured;

iv) adult, breeding birds have an annual mortality of 7%. Farner (1962) gave a minimum of 91% survival and suggested that it might be 95% in a stable population;

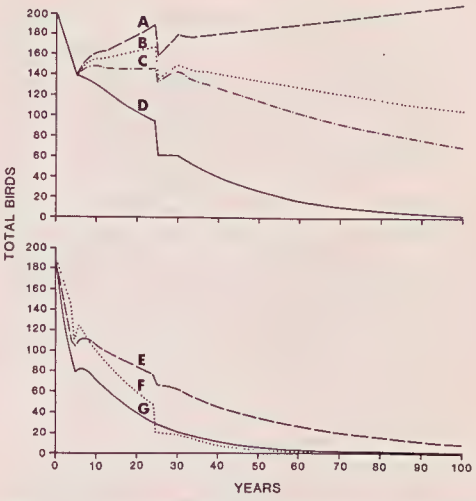

FIG 2 — Comparison of unharvested, theoretical population (A) with populations subjected to young harvested at 10% (B), at 20% (C), at 50% (D); adults harvested at 10% (E), adults harvested at 5% (F); young cropped at 50%, adults at 1%, and eggs at 35% (G). Such additional mortalities are imposed on the other model parameters given in the text.

v) all birds have a potential life expectancy of 30 years. Harris (1966) gave 29 years as the maximum age reached by *Puffinus puffinus* and Serventy (1974) considered that the mean expectation of life in *P. tenuirostris* was about 21 years. More recently Serventy and Curry (1984) suggested that generation time exceeded 30 years. (In the present model, the instant elimination of birds in the ultimate age group results in a population drop at 24–25 years. This trend may be minimised by the introduction of other age groups in the pioneering colony or the insertion of variously-aged immigrants, as may the initial decline due to the absence of breeding birds entering the model population);

vi) one egg per pair of adults is laid each season. Of these 70% hatch and 68% of the young produced survive to fledge and enter the pre-breeding group, thus approximating to results obtained on Green Island between 1965 and 1968 (Norman 1970a). (These data, when used in concert with those for the pre-breeding group, suggest that the adult mortality rate should be slightly higher, for a stable population, to balance the influx of young produced. Though accepted in

this model, presumably all parameters require further refinement. Indeed, P. Curry *pers. comm.* suggests that both the adult mortality rate and that of the pre-breeding group should be reduced. He notes too that age-dependent mortality is demonstrable in this species).

In this model population it is assumed that emigration of nesting birds to breed elsewhere exists (see Serventy 1967), often at a relatively high level (Serventy & Curry 1984), but is balanced by immigration from other sites. There is neither senility nor sexual discrimination in this population which expands slowly after several generations (A in fig. 2), reaching 209 birds after 100 years.

RESULTS AND DISCUSSION

From studies elsewhere in the Furneaux Group, Serventy (1961, 1974) considered that birders took between 19.6 and 63.4% of the young produced in commercially-operated colonies, though he did suggest that it might be higher. Thus the annual population of fledging birds in the hypothetical population has been cropped at 10, 20 and 50% and compared with the unharvested population (fig. 2). Clearly cropping of young birds affects the population growth, and at around 10% the population declines (to reach 52.6% of its original size in 100 years) becoming more rapidly extinct when harvesting approaches 50%. Again, if breeding adults are taken, then the model population declines and becomes extinct. A 1% increase in this model reduces the population to 8 birds after 100 years. Indeed, increases in the annual adult mortality presents perhaps the major influence on this model population's size, as it does in natural populations of other sea birds (Nelson 1980). Removal of eggs, thereby decreasing the effective hatching rate, does not affect the population to the same extent when applied in the absence of other harvesting. However, the cumulative effect of collecting eggs and harvesting adults and young is catastrophic. Since the cropping approximations used in the model are conservative by comparison with recent estimates for the harvesting of young birds alone, (Skira and Wapstra (1980) estimated that between 83.2 and 96.3% of the fledging birds were harvested, during licensed seasons, in some heavily-worked colonies), and since no losses are attributed to disturbance of adults incubating eggs or rearing young, it is not surprising that declines in the breeding population occurred on Big Green Island, and on other islands in the Furneaux Group.

Though it is improbable that complete trade totals for this species will be reconstructed, and though totals taken for local, private consumption will remain unknown, it is nevertheless clear that enormous numbers were harvested in the Furneaux Group. Whilst Lord (1908) estimated the magnitude of the harvest of the 1908 season and gave earlier details, the harvesting of adults, young and eggs had begun years before. Certainly at Green Island, aboriginals from Flinders Island were gathering substantial amounts of eggs and birds by the 1830s (Davies 1846, Brownrigg 1872). If over-harvesting was initiated then, and was intensified when the island was permanently occupied, then there is little doubt that this would result in declines in the numbers of birds breeding by 1893 when Campbell (1900) reported on the state of the colonies. If the birder operating in the 1870s (Lord 1908) was taking 50% of the population of young, then the breeding population on the island would have exceeded 125,000; by 1907, again using model parameters, it would have declined to about 4,000. Increasing restrictions placed upon those involved in the taking of birds privately or for trade in the more limited seasons (including the banning of collecting eggs and adults) resulted in the harvest being centred around young birds. Although the take from the Furneaux Group still exceeded 900,000 in 1930, totals have generally decreased since (Naarding 1980).

Reduction of cropping of adults, young and eggs, and the eventual decline of harvesting of young would alter population expansion. In this regard it is of note that Sharland (1956) reported that the numbers and colonies of shearwater showed increases in the early 1940s and Serventy (1974) considered that the expansion took place somewhat earlier and that it is still continuing. Such expansion may of course have been assisted by the removal of native scrub, which occurred on many islands in the Furneaux Group, and its replacement by a ground-cover more amenable to burrowing birds. It is not, therefore, necessary to involve grazing stock, particularly sheep, as the causative agent in localised population declines of *P. tenuirostris*; rather that over-harvesting of various stages of the shearwater's life provides an adequate explanation. Such a proposition was alluded to years ago by Baker (1909), Belcher (1914) and others, and it has been repeated recently by Skira and Wapstra (1980) with respect to heavily-harvested colonies in Tasmania. Indeed the latter authors noted that the influence of increased harvesting, particularly at non-commercial colonies, may be recognised only some time later when the population decline "could be sudden and dramatic". Early birders, knowing little of the ecology of the species and nothing of its delayed maturity and low adult mortality, would have been unaware that their practices could lead to the destruction of the resource itself.

ACKNOWLEDGEMENTS

The model used here was initially developed by M. Legge, and later modified by M. Mobley and L. Watson. To these I express my gratitude as I do to Mr P. Curry, Department of Agriculture, Western Australia, for his comments on the draft manuscript. Field work on Big Green Island was supported by the Frank M. Chapman Memorial Fund and the M.A. Ingram Trust.

Mr. H.B. Blundstone (Whitemark) provided every assistance and hospitality in travel to and from the island, and accommodation on it.

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and Published by the Society

Hobart, Tasmania

September 1986

Volume 120

MUSEUM OF VICTORIA
31 OCT 1986
NATURAL HISTORY

A. B. CAUDELL, Government Printer, Tasmania

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MUSEUM OF VICTORIA
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NATURAL HISTORY

PAPERS AND PROCEEDINGS OF THE ROYAL SOCIETY OF TASMANIA

Volume 120

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ROYAL SOCIETY OF TASMANIA

ANNUAL REPORT FOR THE YEAR 1985

The Council has the honour to present to members the following report on the activities of the Society during the year.

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Mr R.J. Dwyer

Honorary Editor
Dr M.R. Banks

Honorary Assistant Editor
Dr S.J. Smith

President

Sir James Plimsoll took the Chair, as President of the Society, at the Annual General Meeting in March.

Annual Meeting

At the Annual Meeting on 5th March, Dr J.E.S. Townrow retired as VicePresident and Mr A.V. Brown and Dr P.W. McCartney as Members of the Council. The following were elected:

Vice-President	Dr P.W. McCartney
Members of Council	Prof. J.V. Lovett
	Prof. O.M. Roe
Honorary Secretary	Mr D.R. Gregg
Honorary Treasurer	Mr T.A.H. Knight
Honorary Auditor	Mr R.J. Dwyer

Membership

The Membership is 438, a decrease of 26, and is made up as follows:

	Northern Branch	Total
Honorary Life Members	2	6
Life Members	10	34
Ordinary Members receiving the Papers and Proceedings	62	268
Ordinary Members not receiving the Papers and Proceedings	60	112
Associate Members	14	18
	148	438

Council Meetings

The Council met five times during the year with Mrs G. Morris and Mr C.B. Tassell representing the Northern Branch on the Council.

Amendment to Rules

At a Special Meeting on 2nd April 1985, Rule 56 was altered to read:

> "The editing of the Papers and Proceedings shall be the responsibility of an Honorary Editor appointed by the Council. The Honorary Editor shall be *ex officio* a member of the Council."

Committees

The Council has set up four committees to assist with the administration of the Society. These are:

Executive Committee, consisting of the two Vice-Presidents, the Honorary Secretary and the Honorary Treasurer, to conduct the affairs of the Society between meetings of the Council.

Programme and Planning Committee, consisting of the Junior Vice-President, the Honorary Secretary and a member of the Council, to plan the activities of the Society except programmes of branches.

Honours Committee, consisting of the Executive Committee plus the Chairman of the Northern Branch, to make recommendations on recipients for medals, Honorary Life Members and Visiting Members.

Promotion and Recruitment Committee, to be established.

Tasman Peninsula Seminar

Council is planning a seminar to be held on Tasman Peninsula on 1-3 November 1986.

Banks Memorial Lecture

The Council continued to pursue the proposal that the bicentennial of the European settlement of Australia in 1988 be marked by a lecture, delivered in the various States of Australia, honouring Sir Joseph Banks. In November 1985, a major Australian organisation agreed to sponsor the Lecture.

Library

This year the library has operated with a reduced staff owing to study leave and sickness. However, with library routines in place, it is hoped that little or no inconvenience was experienced by users.

During the year 406 members, University staff members and students, and other users signed the visitor's book. A number of significant reference queries were received by the librarian from members and other researchers, both personal and by letter, sometimes requiring lengthy research. In addition, 183 interlibrary loan requests were filled from libraries in Australia and overseas, highlighting the library's valuable collection. Loans from the library number 175.

The binding of the large backlog of Royal Society serials is now almost complete. 988 volumes were bound this year, and from next year, significantly fewer titles will be done.

The year has been extremely busy, any many activities undertaken. A sample of these is described below:

A collection of surplus volumes from the library of the Northern Branch was priced by the librarian, and offered for sale to the membership. After some months, the remainder was sold to a local antiquarian bookshop.

The backlog of monograph and serials cataloguing was processed this year. These volumes are normally accumulated from exchange partners, duplicates lists and donations. In addition, this year, titles from the Northern Branch surplus not already held, were added to the collection. Serials cataloguing, done in-house, resulted in 14 new titles being added. Monograph cataloguing, using both original and purchased records, numbered 23, with some 26 further titles awaiting records.

In September, 294 copies of volume 119 of the Papers and Proceedings were distributed to exchange partners, 54 in Australia and 240 abroad. The author and subject index to volume 119 on cards was printed and circulated to 8 other libraries in Tasmania in October.

The Closed Access room, incorporating the Ernest Clark, History and Closed Access collections, has been carefully re-organised and re-shelved to provide more appropriate storage for the material, and easier access. A thorough shelf check is now being undertaken of all this material.

A leaflet entitled "Bibliography of John Gould's works and works about John Gould, held in the Royal Society of Tasmania Library, with some complementary holdings in the University of Tasmania Library and State Library of Tasmania" has been prepared this year to highlight the important collection of Gould's works held by the library. It will be catalogued and retained as part of the Pamphlet Collection.

Publications

Volume 119 of the Papers and Proceedings was published in July 1985. It contained 14 papers involving 20 authors and covering agricultural, botanical, geological (including geochronological), historical and zoological topics. The papers occupied 107 pages.

The format of the papers was changed to double column, key words as a feature after the abstract were added and a wider variety of fonts used relative to preceding volumes. The changes were made possible by computerised type setting. The aims of making the changes, a more attractive, more legible volume, are thought to have been achieved.

The Society is again indebted to Dr Banks and Dr Smith for their dedicated editorial work.

Lectures

The following lectures were given at General Meetings during the year:

March — "Fanny Cochrane Smith" Ms Julia Clark, Tasmanian Museum and Art Gallery

April — "Soil erosion in Tasmania — a perspective view" Mr L.R. Richley, Department of Agriculture

May — "Stone and a sense of place, the effect of building stone on regional architecture" Dr E.V.R. Ratcliff, Launceston

June — "Tasmania's economic development after the dam" Dr B.S. Felmingham, University of Tasmania

July — "Tasmania's building sandstones — properties, performance and preservation" Mr Peter Spratt, Consulting Engineer, Hobart

August — "Why worry about doing research in Antarctica?" Dr P.G. Quilty, Antarctic Division, Department of Science

September — "An overview of RSI in Australia" Dr Niki Ellis, Department of Health Services

October — "Astronomy in Tasmania and in space" Dr M.D. Waterworth, University of Tasmania

November — "Whale-strandings in Tasmania — how do they relate to theories on the aetiologies of this phenomenon?" Mr B.L. Munday, Department of Agriculture.

A visit was arranged to the Canopus Observatory, University of Tasmania, at Mount Rumney on the evening of 30 October.

Northern Branch

Chairman	Mrs G. Morris
Vice-Chairman	Mr H.S. Payne
Past Chairman	Mr D.G. Hannan
Council Members	Mrs R.M. Cameron
	Mr E. Fist
	Mr B. Pike
Honorary Secretary	Mr C.B. Tassell
Honorary Treasurer	Mr K.E.J. Robinson
Branch Representatives on the Council	Mrs G. Morris
	Mr C.B. Tassell

The Branch Council met four times during the year.

The following lectures were given at General Meetings during the year:

March — "Australian rock wallabies" Prof. Emeritus G. B. Sharman, formerly of Macquarie University

April — "Aspects of life and education in Fiji" Mr Michael Dunphy, Tasmanian College of Advanced Education

May — "Balinese religion" Mr David Barratt, Queen Victoria Museum and Art Gallery

June — "The Abt railway" Dr John Cannell

July — "Alzheimer's Disease and related disorders" Dr Andrew MacLaine-Cross, Launceston General Hospital

August — "The potential for farming fur animals in Tasmania" Dr Michael Statham, Department of Agriculture

September — "Aquaculture in Australia" Dr Nigel Forteath

October — "Small water turbines for electric power generation" Mr John Lemon, Tamar Designs, Deviot

November — "Why investigate wildlife diseases?" Mr David Obendorf, Department of Agriculture

December — Members' Night "Why laugh?" Mr H.S. Payne
"Royal Society excursions from the late 1950's onwards" Mrs E.M. Barratt

"Industrial archaeology of western Tasmania" Mr W.E. Badcock "Illuminated entertainment using an early lantern projector and numerous animated lantern slides" Mr A.T. Orr

Nominees to Other Bodies

The Council elected Mr A.R. Neilson and Dr P.G. Quilty to the Board of Trustees of the Tasmanian Museum and Art Gallery. They report on the year's activities:

The 1985 State Budget provided $1 158 000 to the Tasmanian Museum and Art Gallery, an increase of 9.2% over the allocation in the 1984 Budget. However, all this increase is committed to pay higher salary and related costs resulting from a review of salaries by the Public Service Board. Expenditure, other than salaries, will have to remain at the same level as in 1984-85.

The Budget allocation has not permitted the employment of any extra staff. This will set problems in keeping some display areas open to the public as more staff are urgently needed to maintain adequate levels of security both at Hobart and at Zeehan. Extra curatorial staff are urgently needed to maintain and expand the service provided to the people of Tasmania and to people elsewhere.

The Community Employment Programme has provided funds to employ five otherwise unemployed people to assist with various projects, both at Hobart and Zeehan. An Aboriginal trainee, funded under the National Employment Strategy for Aboriginals has been employed in the Anthropology Department.

The Trustees, in November 1985, welcomed the start of building operations to complete the renovation of the Queens Warehouse and the construction of a new building to provide an entrance to the Museum and Art Gallery in Macquarie Street.

At Zeehan, the newly renovated first floor of the Zeehan Post Office building has provided much-needed extra exhibition space for the West Coast Pioneers' Memorial Museum. New displays in the George Smith Rooms were opened by the Premier on 27 April 1985.

The Art Foundation of Tasmania, established in 1984, has encouraged support from the private sector for acquisitions for the collections of the Museum and Art Gallery. The Foundation has enrolled 20 individuals and 14 organisations as Members and 3 individuals as Fellows. The Foundation made its first purchase in April 1985 with the acquisition of *Sunrise at Matlock*, an oil painting by John Glover, 1840. Later in the year, two oils by Edith Holmes, *Summer* (1930's) and *Zinc Works* (1940's), and a set of bank notes, printed in 1881 for the Bank of Van Diemens Land Ltd, were purchased. The Art Foundation, together with the Friends of the Tasmanian Museum and Art Gallery established in 1982, has involved the Museum and Art Gallery increasingly with the Tasmanian community. The Trustees are initiating moves to increase further this involvement with the corporate sector in particular.

During the 1985 year, 119 634 people visited the Tasmanian Museum and Art Gallery, compared with 156 651 in 1984. The high figure for 1984 reflected the popularity of the Americas Cup shown in December and January 1983-84.

A selection of 55 works by Simpkinson De Wesselow (1819-1906) from the Royal Society of Tasmania collection, after its showing in Hobart in December 1984 to February 1985, was sent on tour to the Queen Victoria Museum and Art Gallery, Launceston (February-March), the S.H. Ervin Gallery, Sydney (May-June), and the Newcastle Region Art Gallery (October–November). The watercolours and drawings are now safely back in Hobart.

An active programme of temporary exhibitions has been maintained, and this has included *John Passmore Retrospective* (February-April), *Noel Counihan, Fifty Years of his Art* (April-May), *Six Contemporary Artists* (June), *Sengai, The Zen Master* (July-August), *New Works on Paper* (August–September), *G.T.W.B. Boyes, Drawings and Watercolours* (October-November), and *Sullivans Cove, Birthplace of a Colony* (November–).

An important bequest of some 6 500 Australian ceramic items, together with $30 000 to purchase additional pots, was received from the late Brian Everard Easterbrook (1925-1985) of Gravelly Beach. Under the provisions of the *Museums (Aboriginal Remains) Act* 1984, the Tasmanian Aboriginal skeletal remains from Oyster Cove, known as the Crowther Collection, were cremated at Oyster Cove on 4 May 1985.

Dr J.E.S. Townrow was re-elected by the Council to serve a further term on the Board of Trustees of the Royal Tasmanian Botanical Gardens. She reports on the year's activities:

An increase of 8.5% in the number of visitors to the Gardens (247 942) reflected the continuing efforts of Superintendent Tony May and his staff to upgrade the Gardens displays during the year. In the first two weeks of September alone, over 16 000 came to see the magnificent conservatory display

augmented with tulips for Fathers' Day. Some 2 500 came to the Teddy Bears Picnic in November. A State Government Grant of $835 000, of which $681 975 was for salaries etc., was augmented by special grants from the Hobart City Council of $5 000 for the Japanese Garden, maintenance for the Gardens at Parliament House and the Supreme Court, CEP grants for the Japanese Garden construction and a driver for the Hortotherapy Bus, and National Trust Preservation Fund donations totalling $13 000 for reroofing and repair of eaves of the Museum (formerly the Superintendent's Cottage). Cuts in funding have so far precluded publication of the history of the Gardens written by Marcus Hurburgh, former Trustee (Royal Society) and retired Information/Education Officer.

The Gardens' educational policies have been well served during the year by Alan Gray, Information/Education Officer, Pat Hewitt, Hortotherapist, and Sue Wells, Plant Recording Officer.

Mr Gray instructed 3 500 children from 86 schools, a 31% increase on 1984, coming from all over Tasmania, including Launceston, Queenstown, Strahan, Ulverstone, Kempton, Mathinna, Somerset, New Norfolk and Bruny Island. Many other school children came on a casual non-arranged basis. 520 adults participated in guided tours and talks and 70 teachers were given special training seminars. The Education Department has given enthusiastic support to the Gardens' Education Programme and has produced a Schools Garden Excursion brochure.

Some 23 000 people visited the Museum in spite of an enforced three months closure while the roof was replaced and a new display area was remodelled to feature plant evolution, structure and function. Over 1 100 viewed the two-day Bonsai display in October. A popular fern display was replaced in September with an equally interesting display of grasses and grass-like plants. Mr Gray has collected a further 30 native species to augment those already established in the Gardens.

Miss Hewitt was appointed as Hortotherapist in May with responsibility to organise and run programmes for disabled people. Since the opening of the Easy Access Tony Seddon Glasshouse by the Minister, the Hon. G.B. Davis, on 18 July. Miss Hewitt has supervised 250 individual visits for people from seven hospitals, community health centres and rest homes. She also arranged the Hortotherapy Bus tours which over the year conveyed some 1 350 people round the Gardens from over 28 homes, hospitals, rehabilitation centres, clubs and respite centres. Sadly the Hortotherapy Van (donated by the Hobart Rotary Club) died of overwork on active service at the end of September. A replacement van is to be funded by Treasury.

Both Mr Gray and Miss Hewitt are severely hampered in their Gardens activities by the lack of an education building in which to house classes, and the Trustees are making continued efforts to find ways of providing such a facility.

Mrs Wells, Plant Recording Officer, has labelled well over 2 500 plants, and all plant accessions are now recorded. A three-year survey plan of the Gardens has been started by the Surveying and Cartography Department of the Hobart Technical College. This will enable each major plant to be located in the grounds.

There has been mixed progress in major construction project during 1985. The Japanese Garden, funded and supplied with labour substantially by the Commonwealth Community Employment Programme, is well advanced and should be finished early in 1986. Not so the No.4 glasshouse and old cactus glasshouse, both of which are in a very dangerous condition. Twelve years have elapsed since the Board first approached the Minister for funding, and plans were drawn up and approve only to be quashed due to financial restraints which will not permit the scale of the buildings planned. The Board has now to consider minor works of a temporary nature such as a "Cyclone" shed for tools and equipment. Replacement of worn pathways with "Unipave" is also progressing slowly because of budget cutbacks over the year. The Trustees congratulate Dr J. Vitesnik, the Gardens' Landscape Architect, on receiving the Pride of Workmanship Award from the Hobart Rotary Club.

Two of Dr Vitesnik's staff members have been granted Stonemasonry Apprenticeships by the Apprenticeship Commission. They will attend four two-week block release courses in Melbourne for three years. It is noteworthy that, of the total Gardens staff of 32, only seven gardeners are involved in the day-to-day maintenance of the displays.

Chairman of the Board of Trustees, Mr Geoff Fader, resigned on 30 June after 15 years service as a Trustee; the new Chairman elected is Mr Gray J.B. Hulton. The new Board Member appointed by the Governor to replace Mr Fader is Mr Edward C. Chandler, horticulturalist. Thanks go to Professor W. Jackson, University of Tasmania representative, for his 25th year of service on the Board.

Acknowledgements

The Council is grateful for help generously given by many individuals and organisations. In particular, the lecturers, the Government of Tasmania, the University of Tasmania, the Tasmanian Museum and Art Gallery and the Queen Victoria Museum and Art Gallery are specially thanked for their help and cooperation.

I.D. Geard
Senior Vice-President

D.R. Gregg
Honorary Secretary

3 February 1986.

ROYAL SOCIETY OF TASMANIA

Statement of Receipts and Payments for the year ended 31 December 1985

General Account

Balance 1 January 1985		11 506.76	Stationery	348.00
			Insurance	226.57
Subscriptions			Attendants' fees	395.26
258 @ $12	3 096.00		Secretarial fees	1 995.70
104 @ $ 8	832.00		Post box rental	105.00
15 @ $ 5	75.00		Postage and freight	1 256.70
Other years	274.00	4 277.00	Photocopying	40.49
			Subscriptions	762.58
Interest		4 203.08	Repairs and maintenance	17.88
Rent		343.30	Federal debit tax	11.80
Donations		8.00	Telephone	3.93
Sales of publications and Papers and Proceedings		3 122.24	Legal expenses	150.00
			Northern Branch	800.00
Treasury grant		1 800.00	Equipment	700.75
			Sundry expenses, refunds	13.03
				6 827.69
			Papers and Proceedings	2 444.75
				9 272.44
			Balance 31 December 1985	15 987.94
		$25 260.38		$25 260.38

Papers and Proceedings Account

Balance 1 January 1985	1 583.25	Balance 31 December 1985	2 155.33
Interest	572.08		
	$2 155.33		$2 155.33

Accumulation Account

Balance 1 January 1985			63 263.48
Add	Increased cash at bank	5 360.83	
	Net increase in valuation of publications for sale	53.45	5 414.28
			68 677.76
Deduct	Net increase in advance subscriptions	14.00	
	Net transfers to Trust Funds	1 927.03	1 941.03
Balance 31 December 1985			$66 736.73

NORTHERN BRANCH

Balance 1 January 1985	609.86	Subscriptions to Hobart	96.00
Subscriptions	84.00	Printing and stationery	65.54
Suppers	13.88	Theatre hire	110.00
Sale of publications	5.50	Postage	212.42
Grant (Royal Society)	800.00	P.O. Box	21.00
Bank interest	21.83	Batteries for amplifier	8.25
		Sundries	5.50
		Debit tax	3.00
		Balance 31 December 1985	1 012.91
	$1 534.62		$1 534.62

ROYAL SOCIETY OF TASMANIA

Balance Sheet as at 31 December 1985

1984			*1985*
63 263.48	Accumulated Funds		66 736.73
129.00	Subscriptions in advance		143.00
	Trust Funds:		
1 901.95	— Clive Lord Memorial Fund	2 088.03	
3 191.57	— A.N. Lewis Memorial Fund	3 503.48	
1 447.39	— Morton Allport Memorial	1 592.74	
573.42	— A.A. Clark Bequest	627.36	
3 904.18	— Joseph Milligan Bequest	4 276.70	
2 081.29	— R.M. Johnston Memorial Fund	2 322.54	
925.78	— Henry Oliver Bequest	1 017.26	
2 121.41	— W.H. Hudspeth Memorial	2 328.64	
3 423.43	— Life Membership Fund	3 740.70	21 497.45
$82 962.90			$88 377.18
	Represented by:		
33.00	Cash on hand		33.00
	Cash at bank:		
11 506.76	— General account		15 987.94
1 583.25	— Papers & Proceedings Account		2 155.33
403.47	— Clive Lord Memorial Fund		534.54
572.37	— A.N. Lewis Memorial Fund		748.87
860.00	Mortgage Loan		860.00
	Commonwealth Treasury Bonds &		
29 900.00	Inscribed Stock (at cost)		29 900.00
7 000.00	Interest Bearing Deposits		7 000.00
15 000.00	Library (at valuation for insurance)		15 000.00
16 104.05	Publications (at selling price)		16 157.50
$82 962.90			$88 377.18

The Society owns works of art which have been donated over the years and which do not appear on the Balance Sheet. They are all housed in the Tasmanian Museum and Art Gallery and are covered by that organisation's insurance. A catalogue is available to members listing these works of art.

MUSEUM OF VICTORIA
3 1 OCT 1986
NATURAL HISTORY

FIELD PROBLEMS OF RADIOCARBON DATING IN TASMANIA

by Eric A. Colhoun

(with two tables and one text-figure)

COLHOUN, E.A., 1986 (12:ix): Field problems of radiocarbon dating in Tasmania. *Pap. Proc. R. Soc. Tasm.* 120: 1-6. ISSN 0080-4703. University of Newcastle, Newcastle, N.S.W., Australia, formerly University of Tasmania.

Radiocarbon dating of Late Quaternary deposits has shown that erosion of old organic materials and their redeposition in younger sediments may give ages that are too old. Also, the humid climate and leaching pedogenic environment of much of Tasmania permits translocation of young humic acids down profile through porous sediments. The humic acids may then be perched by impermeable clay horizons or may be adsorbed/absorbed by older clay and organic materials to give ages that are too young. These problems are illustrated by examples.
Key Words: radiocarbon, redeposition, translocation, humic acids.

INTRODUCTION

During the last thirty years radiocarbon dating has proved to be the most reliable method of dating sequences of Late Quaternary deposits in Tasmania. Errors in radiocarbon dating can be divided into: those related to laboratory processing and the technical limitations of the method, and those related to the judgement of the field scientist and the environmental conditions of the region or site from which the samples have been collected.

Since no radiocarbon dating facilities exist in Tasmania, field scientists depend on mainland Australian laboratories (Mackintosh Centre for Quaternary Dating, University of Sydney; and Radiocarbon Laboratory, Research School of Pacific Studies, Australian National University) or on overseas laboratories for analyses of organic samples. However, the field scientist must have a good understanding of the environmental conditions that have affected the sample before, during and after its deposition until the time of its collection and submission for analysis.

Experience in Tasmania has shown that there are a number of problems, related mainly to climate and environment of deposition, that occur frequently enough to make it worthwhile alerting those likely to use the method in the future. The problems will be illustrated with examples listed in *Radiocarbon Dates for Tasmania, 1956-1984* (Colhoun 1985a). Although the discussion will demonstrate the need for caution in field sampling and in interpreting the results of radiocarbon dating, it does not invalidate the usefulness of the technique. Radiocarbon dating is likely to remain the most significant method for assessing the age of organic deposits back to 40 000 yr BP in archaeological (see Stockton 1981), geomorphological and palynological research for some decades. The discussion will not qualify all dates in the list, the details of which are either indicated in the publications or available from the authorities cited.

DISCUSSION

The problems encountered in analysing field sections that contain organic deposits result from the inclusion of older organic materials in younger deposits, and from the contamination of older organic materials by younger organic carbon. In the prevailing cool humid and perhumid climate of western Tasmania (Gentilli 1972) the first problem is mainly a physical one caused largely by erosion of old deposits and soil profiles from the landscape and their partial inclusion in young deposits. The second problem is mainly chemical and biochemical. It is related to the partial decay of organic materials, the leaching of humates through inorganic materials, the adsorption of humic acids by clays, and the adsorption/absorption of humic acids by old organic materials.

The problem of inclusion of old materials in young deposits has occurred for marine shells, wood, charcoal and soil organic matter. The problem with marine shells was first suspected when shells from beach sand underlying a dune at The Jam near Smithton (fig. 1) were submitted by N. Stephens to Gakushuin University Radiocarbon Laboratory and assayed at 22 700 ± 1 100 yr BP (Gak 652) (Kigoshi & Kobayashi 1966). The assay was considered to indicate that the shells were probably of interglacial age and that the age was

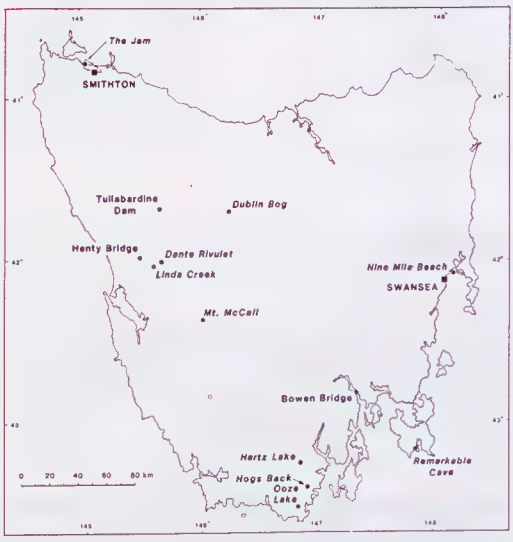

FIG.1 — Locality map.

near the limit of dating carbonate material at the time (Stephens, pers. comm.). Observations of the marine plains and shallow offshore banks west of Smithton by van de Geer (1981) showed that the Holocene transgression eroded interglacial marine deposits and redeposited them. Thus, shells derived from the interglacial deposits would be included with Holocene age shells in mixed-age assemblages. Samples of shell from the base of Holocene marine sequences on gently shelving coasts could, therefore, produce age assays that may not indicate whether the deposits are of interglacial or Holocene age.

Drilling and sampling of the Holocene Nine Mile Beach barrier system north of Swansea in eastern Tasmania by Thom *et al.* (1981, pp.19-20) has mainly given conventional ^{14}C ages of between 8 130 ± 110 yr BP (SUA 1 296) and 10 900 ± 130 yr BP (SUA 1 293) for shell hash samples. These assays on samples that occur between +1 and −2 m from m.s.l. cannot be taken as the ages of marine sedimentation by the Holocene sea, which to judge from the envelope of relative sea levels for eastern Australia (Thom & Roy 1983) had maximum altitudes of between −8 and −45 m during this time. Only one assay of 5 310 ± 90 yr BP (SUA 1 291) falls within the expected time range of 7 000 yr BP for deposits within 3 m of modern m.s.l. This sample was nearest the seaward margin of the barrier. It seems clear that shells of interglacial age have been incorporated within the samples, a problem that has been encountered in the dating of shelly marine deposits elsewhere in southeastern Australia (Donner & Jungner 1981).

At Ooze Lake in southern Tasmania a ^{14}C age of 17 700 ± 400 yr BP (SUA 1 359) has been obtained from charcoal and finely divided organic material in a core of lake clay between 6.40 and 6.65 m depth (table 1). This age is by far the oldest date in Tasmania for the apparent deglaciation of high altitude (900–1 100 m) cirque basins that were occupied by ice during the last glaciation. Dates obtained from the basal sediments or from the lowest organic sediments in other cirque and rock basins in central and western Tasmania are between 13 000 and 9 000 yr BP. At lower altitudes a basal date of 13 400 ± 600 yr BP (SUA 2 188) has been obtained from lake sediments behind the end moraine at Dublin Bog (600 m) in the Mersey Valley. These dates compare with the date of 12 590 ± 230 yr BP (SUA 1 943) from 5.50 to 5.70 m depth at Ooze Lake (Macphail & Colhoun 1985, Colhoun 1985a, Macphail & Peterson 1975). The question of whether or not the basal date of 17 700 yr BP really represents very early deglaciation in eastern Tasmania cannot yet be fully answered. The date, however, seems extremely early since there is evidence for ice being near its last glaciation limit in western Tasmania at Dante Rivulet at 18 800 ± 500 yr BP (ANU 2 533) (Kiernan 1983, Colhoun 1985b), and in the Mersey Valley slightly before 13 400 yr BP as indicated. The possibility that the date 17 700 yr BP does not represent the age of deglaciation must be considered.

Most Tasmanian Late Pleistocene-Holocene lake core sequences consist largely of inorganic grey silts and clays overlain by organic detritus and muds. The former generally represent erosion of an alpine or poorly vegetated environment and are usually deposited quite rapidly (c.f. 3-4 mm/yr^{-1} at Dublin Bog; 1.4-3.6 mm/yr^{-1} at Ooze Lake) whereas the organic detritus/mud generally represents deposition in a well vegetated, shrub or forest environment and is quite slow (c.f. 0.3-0.6 mm/yr^{-1} at Dublin Bog). However, deposition rates can be quite variable for short periods in any core due to local conditions. The rate of 0.2 mm/yr^{-1} between 12.6 and 17.7 ka, at Ooze Lake in extremely low for Late Pleistocene lake clays which usually exceed 1 mm/yr^{-1}.

An abundance of pollen of *Lagarostrobos franklinii* and significant pollen of *Nothofagus cunninghamii* and *Phyllocladus asplenifolius* occur during the earlier part of this time period and could suggest forest conditions likely to give low yields of sediment to lakes. However, the pollen seems mainly to have been transported from adjacent

TABLE 1

Age and Sedimentation Rates of Two Post-glacial Sequences in Tasmania

Ooze Lake, altitude 880 m			Dublin Bog, altitude 600 m		
Depth (m)	Age (ka)	Sedimentation rate (mm/yr^{-1})	Depth (m)	Age (ka)	Sedimentation rate (mm/yr^{-1})
0-1.1	5.4	0.2	0-2.2	4.4	0.5
1.1-2.1	8.9	0.3	2.2-3.2	7.3	0.3
2.1-3.1	10.4	0.7	3.2-4.2	8.9	0.6
3.1-4.1	10.7	3.6	4.2-5.2	10.7	0.6
4.1-4.9	12.1	0.6	5.2-6.3	11.7	1.1
4.9-5.6	12.6	1.4	6.3-6.8	12.9	0.4
5.6-6.6	17.7	0.2	7.5-8.5	13.4	4.0

lowland sources (Macphail & Colhoun 1985). In the later part of the period pollen indicates that grasses, composites and sclerophyll shrubs were locally important, with *Casuarina* and chenopod pollen being transported to the site from external sources. The local vegetation appears to have been alpine heath which is unlikely to have reduced erosion to very low rates.

Counts of charcoal particles of >20 μm diameter indicate that they are two to three times more abundant below 5.8 m in the Ooze Lake core than above that depth. It is hard to envisage how so much charcoal could occur in this situation unless there was either abundant burning or relatively rapid erosion of a soil surface that contained significant quantities of charcoal. If abundant burning occurred it is likely that sedimentation rates would have been high which is not consistent with the data. If erosion of soil material bearing stored charcoal from the adjacent slopes into a newly available site for deposition had occurred on deglaciation, the basal date obtained from the core could precede the age of deglaciation. Though it is impossible to conclude with certainty that this happened in the manner stated, nevertheless, distinct charcoal-rich horizons occur in the basal parts of many Late Pleistocene-Holocene cores and the likelihood of such horizons containing old charcoal is high.

The problem of sediments containing old charcoal is known elsewhere. It is well illustrated in the MacDonald River of New South Wales where the modern flotation load of charcoal has been shown to vary in age between about 650 and 1 550 yr BP depending on particle size (Blong & Gillespie 1978). The larger particles are younger and the smaller particles are older. This is an expected result of gradual refinement of size during transport and deposition.

TABLE 2

Radiocarbon-dated Sediments at Tullabardine Dam, Tasmania.

Depth (m)	Material	Age (yr BP)	Lab. No.
0.60-0.65	Wood	440 ± 60	SUA 2 279
1.20	Peat	8 030 ± 110	SUA 2 185
1.35	Peat	11 060 ± 210	SUA 2 186
1.60	Wood	11 660 ± 150	SUA 1 044
1.90-2.10	Organic soil	21 250 ± 270	SUA 1 045
2.50	Trace organic carbon	10 730 ± 660	ANU 4 816
3.05-3.10	Wood	31 500 ± 900	SUA 1 046
2.80	Wood	>43 800	SUA 1 047

The erosion of old wood fragments and their deposition within younger sediments is known from Henty Bridge in western Tasmania where a section through a former small lake-basin shows slope deposits overlying and interdigitating with organic clays that rest on till (see fig. 2 in Colhoun 1985c). The radiocarbon dates on organic mud and wood from the centre of the lake basin produced an acceptable way-up sequence of ages from >34 600 yr BP (Gak 5595) to <23 640 ± 1 030 yr BP (Gak 5597) for the deposits. However, where the slope deposits were interstratified with the organic clays near the margin of the lake the radiocarbon assays on wood fragments were inverted with a sample dated to 23 860 + 890 yr BP (Gak 5 594) underlying deposits with a sample dated to >34 190 yr BP (Gak 6 296).

The inversion of ages can be interpreted as resulting from destruction of a soil profile bearing wood fragments. The surface debris and youngest wood would be eroded and redeposited before the more deeply buried older wood. In the humid regions of western Tasmania, a standing rootstock of *Telopea truncata* at 0.5 m depth in peat at Hogsback has an age of 750 ± 60 yr BP (SUA 2 110), and partly buried *Athrotaxis* wood at Mount McCall has an age of 2 740 ± 60 yr BP (SUA 2 108) (F. Podger, pers. comm., see Colhoun 1985a). It seems likely that derived fragments of older wood will be encountered in numerous deposits.

The problem of young sediments giving apparently old radiocarbon ages is illustrated not only by derived shell, charcoal and wood but also by erosion of organic matter from the A horizons of soils. Study of estuarine sediments at Bowen Bridge on the Derwent River showed that the Late Holocene (4 500-0 yr BP) clays were extremely rich in colloidal organic matter (10-22.5%). These clays were deposited by salt-water flocculation of suspended river sediments. The clays include sparse lamellibranchs throughout their 26 m thickness. Radiocarbon dating showed a lack of correlation between assays made on samples of shell and organic mud. Samples from the same horizon (-29.5 m below sea level) differed by as much as 2 930 yr (shell 4 440 ± 150 yr BP, SUA 1 964; organic mud 7 370 ± 140 yr BP, SUA 1 965) and a sample of organic mud from -19 m was assayed as 1 020 yr BP older than a shell sample from -26.3 m (mud 3 080 ± 80 yr BP, SUA 1 962; shell 2 060 ± 150 yr BP, SUA 1 963).

Although currents on the bed of the estuary might have been responsible for erosion and redeposition of the organic muds, it is to be expected that they would also be capable of eroding and redepositing the shell materials. The shells found within the muds showed no evidence of abrasion, which seemed to indicate that once deposited they remained there while the estuarine clays accumulated at average rates of 8-12 m (uncompacted sediment; 5-8 m compacted) per ka. This indicates that the younger radiocarbon dates obtained from the shells give the age of deposition. It also points to the colloidal humate in the muds being derived, along with abundant charcoal fragments, from soil organic materials in local catchments where the vegetation was frequently burnt by aborigines after 6 000 to 5 000 yr BP (Colhoun & Moon 1984). The second major cause of error in radiocarbon dates arises from the contamination of old organic material by young organic carbon, mainly as humic acids which drain through porous sediments but accumulate if the deposits are impermeable. Samples usually can be pretreated to remove contaminant humic acid. However, with small samples of finely divided organic matter pretreatment may sometimes not be practical. In such cases the presence of humic acids may result in a date being obtained that is considerably younger than the age of the sample. In the wet leaching pedogenic environments of southern, central and western Tasmania, samples are known to have been contaminated by (a) the perching of young humic acid at the base of a core by impermeable materials, (b) the perching of young humic acid within a section by an impermeable horizon, (c) the adsorption/absorption of young humic acid by clay/charcoal, and (d) the absorption of young humic acid by wood. Examples of these are discussed below.

A 1.9 m core of peat and clay deposits, extracted from a small lake that overlies till and is adjacent to Hartz Lake at 950 m altitude in southeastern Tasmania, gave an age sequence of 2 930 ± 100 yr BP (SUA 1 357), 4 100 ± 200 yr BP (SUA 1 944) and modern (SUA 1 945) for depths of 0.5-0.59 m, 0.71-0.9 m, and 1.6-1.89 m respectively (Colhoun 1985a).

Pollen analysis of the core shows that the sediment commenced accumulating during the Late Pleistocene and that deposition was probably continuous during the Holocene. However, the radiocarbon assays show that the basal sample was contaminated by modern humic acids that were perched by the subjacent till and adsorbed/absorbed on the clays/finely divided charcoal near the base of the core. The implications of the draining of humic acids through the sediments is that organic samples from higher levels may also contain some young humic acid that will give

assays less than the age of the sediments.

In the natural temperate rainforest environment at Tullabardine Dam in western Tasmania a sequence of 4 m of peat and lake sediments gave a dated pollen sequence that is consistent with expected ages for an interstadial, maximum last-glaciation and Holocene vegetation history (table 2), except for the assay of 10 730 ± 660 yr BP at 2.5 m (Colhoun & van de Geer, unpublished). Only very small amounts of organic carbon were obtained from this sample. The result suggests contamination by young humic acids that were probably perched by the silty clays and adsorbed/absorbed by the clay and finely divided organic matter.

Why the other samples should appear to give reasonable age estimates and this sample appear to be strongly contaminated is not clear. It may be related to the ratio of contaminant humic acid being high in the small sample whereas the same amounts would have much less effect in the larger samples, even though the dates would provide younger than real ages. However, the age difference could also wholly or partly have been caused by young humic acids translocated through the peat, buried soil and mineral horizons being perched by the impermeable silty clay. Perching within sequences by impermeable beds seems as likely as basal concentration by underlying materials.

In addition to the perching of humic acids near the base or within sediment sequences, humic acids may be directly adsorbed onto or absorbed into organic matter and may not be removed completely by pretreatment, especially if only hydrochloric acid is used.

At Remarkable Cave in southeastern Tasmania charcoal fragments from the base of 17 m of slope, gully-fill and cliff-fall deposits overlying an interglacial beach were assayed at 29 000 ± 2 000 yr BP (SUA 154). In an attempt to date higher levels in the deposits, five samples of wood and peaty organic materials were assayed and all were found to have ages greater than 37 000 yr BP. The higher samples all received acid-alkali-acid pretreatment which largely removed the humic acids from the wood and peaty materials but the first sample (SUA 154) did not receive alkali pretreatment before assay. The charcoal had been contaminated by younger humic acids (Colhoun 1977). The results indicate that if the charcoal sample alone had been assayed after acid pretreatment, the interpreted age of the deposits would not have been correct.

A similar, though more complex, problem was encountered with attempting to date the classic glacial site in the Linda Valley of western Tasmania. Here, till and sandy ice-marginal glacigenic deposits overlie an ancient soil with standing tree stumps that include *Phyllocladus*. An early ^{14}C date of 26 480 ± 800 yr BP (W 323) (Gill 1956) determined on a piece of wood derived from the soil but bedded within the glacial deposits suggested that this represented the age of the last glaciation maximum. An unpublished date of >40 000 yr BP (R 488) on wood from a *Phyllocladus* stump in the soil (M.R. Banks, pers. comm.) cast doubt on the younger result and suggested a contamination problem. In an attempt to resolve the problem, both a whole-wood sample and its -cellulose fraction (the supposedly most stable fraction) were dated at 27 800 ± 700 yr BP (ANU 2 480A) and 23 100 ± 600 yr BP (ANU 2 480B) respectively, and the apparent contamination problem remained. Further dating of large wood-samples from the palaeosol has given an assay of >48 500 yr BP (ANU 3 413), but the stratigraphy, the glacial deposits, reversed magnetisation of associated glacial lake clays, and pollen of Tertiary-type in the buried soil all pointed to an Early Pleistocene or older age (Colhoun 1985b).

In an attempt to ascertain how the wood was contaminated, the $^{13}C/^{12}C$ values were determined using PDB as standard. The whole-wood gave a $\delta^{13}C$ value of -15°/oo and the α-cellulose values of -20 to -22°/oo. Both values are more positive than the typical $\alpha^{13}C$ values for wood of -25 to -34°/oo, and -22 to -23°/oo for α-cellulose (Smith & Epstein 1972, Head, pers. comm.). The positive shift in the α-cellulose fraction is so small that it cannot be regarded as significant. However, the positive shift for the whole-wood sample is large and lies within the -11 to -16°/oo range typical for monocotyledons such as Gramineae and Cyperaceae. Why the apparent age of the α-cellulose fraction should be younger than the other age determinations is not known. The strong positive shift of the $\delta^{13}C$ value given by the whole-wood sample strongly suggests contamination by younger humic acids derived from a monocotyledonous acidic vegetation type. Pollen data indicate that during the last glaciation much of the area was grassland, heathland and sedgeland for considerable periods.

The above examples demonstrate that in the humid environments of Tasmania, with their acid vegetation communities and leached soil profiles, young humic acids may contaminate old samples of organic matter, charcoal and wood, and that ^{14}C assays cannot necessarily be accepted as indicating ages without knowing the detailed stratigraphy of the site and the methods of sample pretreatment. The examples also indicate that it is unwise to

conclude the age of any deposit from the assay of a single sample. It seems necessary to obtain, wherever possible, several samples from different levels in clearly defined stratigraphic successions and if consistent age sequences are not obtained from whole-wood or extract samples then chemically fractionated samples should be dated.

ACKNOWLEDGEMENTS

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(accepted May 2, 1986)

NOTES ON THE DIET OF THE CARNIVOROUS MAMMALS OF THE UPPER HENTY RIVER REGION, WESTERN TASMANIA

By Robert J. Taylor

(with three tables)

TAYLOR, R.J. 1986 (12:ix): Notes on the diet of the carnivorous mammals of the Upper Henty River region, western Tasmania. *Pap. Proc. R. Soc. Tasm.* 120: 7–10. ISSN 0080-4703. Department of Zoology, University of Tasmania, Hobart, Tasmania, Australia 7000.

All four of Tasmania's large mammalian carnivores (*Sarcophilus harrisii, Dasyurus maculatus, D. viverrinus, Felis catus*) occur in the Upper Henty River region, in western Tasmania. A short-term study was undertaken to compare the diet of these species when in sympatry. No data were obtained for *D. maculatus*. The other species overlapped in their use of small mammals. However each species had a major component of the diet (*S. harrisii*, large mammals; *D. viverrinus*, invertebrates and plant material; *F. catus*, birds) which was not utilized by the other species and hence substantial competition between them is unlikely. The diet reported by others for *D. maculatus* is similar to that found for *F. catus*. These two species had similar habit preferences and hence it is possible that competition could occur between the native *D. maculatus* and the introduced *F. catus*.

Key Words: Tasmanian carnivores, mammals, diet.

INTRODUCTION

Three of the larger native carnivorous marsupials (*Sarcophilus harrisii, Dasyurus maculatus and D. viverrinus*) are still widespread and common throughout much of Tasmania (Green 1973). On the mainland of Australia these species are now either extinct (*S. harrisii, D. viverrinus*) or have suffered a major reduction in their distribution (*D. maculatus*). The insular nature of Tasmania has resulted in the native carnivores being free of any possible competition from foxes (*Vulpes vulpes*) or dingoes (*Canis familiaris*) which accompanied the human occupation of the continent. Feral cats (*Felis catus*), however, were introduced into Tasmania and are now widespread (Hocking & Guiler 1983).

The diet of *D. viverrinus* has been examined by Green (1967) in the northeast and by Blackhall (1980) and Godsell (1983) in southern Tasmania. Data on the diet of *S. harrisii* are given by Guiler (1970) for three populations in the northeast, south and west of Tasmania, and by Green (1967) for a population in the northeast. All of these studies were conducted in pastoral areas.

A mammal survey conducted in the Upper Henty River region of western Tasmania showed that all four of the carnivores were present (Taylor *et al.* 1985). Because the area surveyed was remote from human settlement and contained all four species, faecal pellets were collected and used to examine their diet.

STUDY AREA AND METHODS

The study was conducted in the northern part of the Southwest Conservation Area in the Upper Henty River region. The area is not settled but mining exploration and selective logging has taken place and a system of roads and tracks is present. The vegetation types occurring in the area are rainforest, wet scrub, eucalypt scrub, sedgeland and alpine. Further details of the study area are given in Taylor *et al.* (1985).

Trapping was conducted between 6 and 16 November 1983 and between 11 and 21 January 1984. The carnivores were caught in wire mesh traps baited with either day old chicks or meat scraps. Animals were usually kept overnight and their scats collected. Stomach contents from feral cats were also collected. Scats found in the study area which could be confidently identified were also included. Only two of the scats of *Felis catus* and *D. viverrinus* were not from the animals trapped; however for *S. harrisii* only 5 of the 28 scats analysed were from trapped animals.

Hair in the scats was identified using the methods of Brunner & Coman (1974) and the key given in Taylor (1985). The hair of *Pseudomys higginsi* and *Mastacomys fuscus* is difficult to separate (Taylor 1985). No evidence of *M. fuscus* occurring in the study area was found but *P. higginsi* was widespread and abundant (Taylor *et al.* 1985). Thus hair found in the scats which could have come from either of these species was classified

as *P. higginsi*. Any traces of hair from the species whose scat was being examined were not included in the results. Several times the presence of jaw bones in the scat enabled the identification, made on the basis of hair samples, to be corroborated. Birds were identified from feathers. Any traces of chicken feathers or bone from the bait were not included in the results. Invertebrates were identified from exoskeletal remains.

RESULTS

Dasyurus viverrinus were found to feed on invertebrates, small vertebrates and plant material (table 1). Fifty-three percent of the items identified were invertebrates. *Dasyurus maculatus* were captured six times and four scats were collected. Unfortunately all scats contained only bait.

TABLE 1

Frequency of Occurrence of Items in Five Scats from *Dasyurus viverrinus*.

Item		Occurrence
Mammal:	*Rattus lutreolus*	1
	Antechinus spp.	1
Bird		1
Snake		1 (minor)
Insect:	Adult (Orthoptera and Coleoptera)	2
	Larvae — blowfly (*Calliphora stygia*)	1
	— corbie grub (*Oncopera* sp.)	2
	— unidentified	1
Yabbie (*Parastacoides* sp.)		2
Plant material:	Seeds	2
	Unidentified	1 (minor)

Small mammals and birds made up the bulk of the diet of feral cats (table 2). Much of the hair in the scats of feral cats was finely masticated which made identification difficult. The unidentified small mammal listed in table 2 is based on the size of a tibia found in the scats.

For *Sarcophilus harrisii* 78% of the items identified were mammals (table 3). All of the non-mammalian items made up a very small proportion of the volume of the scat. *Pseudocheirus peregrinus* was the most frequently occurring mammal species in the scats. Small species (i.e. rats and mice) made up 45% of the mammalian items

TABLE 2

Frequency of Occurrence of Items in Three Stomachs and Ten Scats from *Felis Catus*.

Item		Occurrence
Mammal:	*Rattus lutreolus*	2
	Antechinus spp.	5
	Unidentified small mammal	1
	Unidentified	3
Bird:	Green rosella (*Platycercus caledonicus*)	4
	Unidentified	2
Reptile		1 (minor)
Insect		1 (minor)

DISCUSSION

The number of scats obtained during the study was limited. However the data have enabled the categories of food eaten to be elucidated. Major differences between the species are indicated.

The most extensive study of the diet of *D. viverrinus* was carried out by Godsell (1983) in southern Tasmania. The percentage frequencies of the major items found by Godsell in the scats of *D. viverrinus* were: insect larvae 84%; mature insects 56%; vertebrates 26%; and vegetation 66%. For the vertebrate prey, mammals were more frequently eaten than birds, with the largest mammal eaten being the rabbit (*Oryctolagus cuniculus*). Godsell (1983) concluded that *D. viverrinus* was an opportunistic predator. The diet of *D. viverrinus* in this study is similar to that found by Godsell (1983).

TABLE 3

Frequency of Occurrence of Items in Twenty-eight Scats from *Sarcophilus harrisii*.

Item		Occurrence
Mammal:	*Thylogale billardieri*	5
	Pseudocheirus peregrinus	11
	Rattus lutreolus	3
	Pseudomys higginsi	4
	Antechinus spp.	6
Bird		2 (minor)
Insect:	Blowfly larvae (*Calliphora stygia*)	2 (minor)
	Adults (Coleoptera)	1 (minor)
Plant material		3 (minor)

Thus invertebrates, particularly insects, were the most frequently encountered items with small vertebrates and plant material comprising the other items in the diet. Yabbies were not recorded in the other dietary studies of *D. viverrinus* (Green 1967, Blackhall 1980, Godsell 1983). It is likely that these animals were far more abundant in the present study area. *D. viverrinus* are known to scavenge when given the opportunity (Godsell 1983). The blowfly larvae found in one of the scats could indicate scavenging in the present study area, however, it is more likely that they were ingested with the bait.

Feral cats fed on small vertebrates. Two-thirds of the birds found eaten by feral cats were green rosellas (*Platycercus caledonicus*). These birds were frequently seen feeding on the tracks in the same vegetation types that feral cats utilized (i.e. rainforest and scrub areas). The presence of green rosellas on the ground, in open areas where they could be easily stalked, would increase the susceptibility of this species to predation in comparison with other birds. Other studies have also found that feral cats feed mainly on small vertebrates, up to the size of the brushtail possum *Trichosurus vulpecula* (Jones & Coman 1981, Brunner *et al.* 1981).

Sarcophilus harrisii has been reported to feed on a wide variety of foods with most of the large and medium-sized prey considered to be scavenged (Green 1967, Guiler 1970). The majority of the food of *S. harrisii* has been found to be mammalian (*op. cit.*). This is also the case in the present study area. Small mammals, ringtail possums (*Pseudocheirus peregrinus*) and pademelons (*Thylogale billardieri*) were found to be eaten by *S. harrisii*. In the pastoral areas, where the diet of *S. harrisii* has previously been examined (Green 1967, Guiler 1970), carrion is abundant due to the presence of domestic stock and native mammals that have been killed on the roads or as pests. *S. harrisii* is considered to be an inept killer that scavenges rather than hunts (Buchmann & Guiler 1977, Guiler 1983). Because of the isolated nature of the study area, carrion resulting from human activities is likely to be uncommon. Blowfly larvae were found in two scats. One of these was from a trapped animal and could have come from the bait. The other was from a scat picked up in the area; thus some of the items eaten by *S. harrisii* in the study area may be scavenged. However I consider it unlikely that all of their diet could be obtained in this way.

In the Lower Gordon River region Hocking & Guiler (1983) concluded that *S. harrisii* was confined to areas bordering the major rivers. The density of vegetation may impede prey capture in this region. In the present study area, in contrast to the Lower Gordon River region, roads and tracks are abundant. These are used extensively by *S. harrisii* for movement (Taylor *et al.* 1985). *S. harrisii* is probably too slow to run down its prey (Guiler 1983), however the roads could be used for stalking. *S. harrisii* may be able to closely approach animals present on or near roads and hence use the element of surprise to successfully kill their prey. Pademelons were frequently seen feeding along the sides of the roads (Taylor *et al.* 1985).

The ringtail possum is largely an arboreal species (Thomson & Owen 1964) and hence its frequency in the diet of *S. harrisii* is surprising. Guiler (1970) found ringtail possum remains in 17% of the stomachs examined from a population in southern Tasmania. Guiler (1970) claimed that *S. harrisii*, especially younger animals, can climb trees. The femur of a ringtail possum found in the scats was from a young animal, possibly taken from a nest. However these animals may be killed on the ground. An individual was seen in the study area crossing a creek via a road bridge.

Although sample sizes in the present study are small, the categories of prey included in the diet of the species examined are in accord with that found by others in more extensive studies in other areas. It is thus considered that comparisons between the species are justified. The three species for which data were obtained were found to overlap most in their use of small mammals (i.e. *Rattus lutreolus*, *Pseudomys higginsi*, and *Antechinus* spp.). However each species had a major component of the diet (i.e. *S. harrisii*, large mammals; *Felis catus*, birds; *D. viverrinus*, invertebrates and plant material) which was not utilized by the other species. The habitat preferences of *D. viverrinus* also differed from that of the other carnivores (Taylor *et al.* 1985). Hence it is unlikely that substantial competition for food was occurring between these species. No data on the diet of *D. maculatus* were obtained. Edgar (1983) and Godsell *et al.* (1984) reported that their diet included birds, rats and other small terrestrial and arboreal mammals. This is a diet which is similar to that found for *F. catus* in this study. The habitat preferences of *D. maculatus* and *F. catus* were also found to be similar (Taylor *et al.* 1985). It is thus possible that competition could occur between the native *D. maculatus* and the introduced feral cat. More detailed research on the effects of feral cats on the native fauna is obviously warranted.

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(accepted Dec. 9, 1985)

A NOTE ON AIR TEMPERATURE LAPSE RATES ON MOUNT WELLINGTON, TASMANIA

by M. Nunez and E.A. Colhoun

(with three tables and one text-figure)

NUNEZ, M. & COLHOUN, E.A., 1986 (12:ix): A note on air temperature lapse rates on Mount Wellington, Tasmania. *Pap. Proc. R. Soc. Tasm.* 120: 11–15. ISSN 0080-4703. Department of Geography, University of Tasmania, Hobart, Australia, and Department of Geography, Newcastle University, Newcastle, Australia.

Temperature lapse rates are derived from field measurements taken on Mt Wellington over a one year period. The results are compared with regional lapse rates for the state. The agreement is best with maximum temperatures in winter and minimum temperatures in summer. The agreement is poor with other combinations. This is due to oceanic and continental effects.

Key Words: temperature lapse rates, Tasmania.

INTRODUCTION

The gradient of air temperature with altitude, commonly known as the environmental lapse rate (ELR), is a widely documented phenomenon (see Barry 1981). Many factors influence the ELR and mainly involve thermal characteristics of surface features such as topography, vegetation and soil type. In general these factors make the ELR very site-specific requiring, in most cases, direct experimental measurements, (Richardson & Linacre 1977; Tapp 1978; Kernich & Robin 1979; Manins & Sawford 1979). Of more applicability to ecological and palaeoclimatic work is the change in near ground level air temperature with terrain altitude (Macphail 1979; Kirkpatrick 1982; Colhoun 1985). This form of ELR, to be distinguished from "free air" ELR, is sometimes used as an aid in palaeo-environmental reconstructions. However, little attempt has been made to distinguish between and compare temperature lapse rates obtained from a single steep mountain slope with regional lapse rates that are generally obtained from measurements taken at individual stations often located in different topographic situations in highland areas. It is the purpose of this paper to investigate, using air temperature measurements taken at Mt Wellington, the relationship between lapse rates on a single north-facing mountain slope and those obtained from Tasmanian climatological stations.

DATA

Daily maximum and minimum temperatures, grass minimum temperatures and thermograph records were obtained at six stations that extend from sea level to the summit of Mt Wellington (table 1). The study period extended from April 1, 1978 to March 31, 1979.

All sites with the exception of the Chalet had a good sky view. The environment surrounding the Chalet site was lightly forested, but the equipment was placed in an opening with scrub which not only gave a good sky view but was fairly representative of the general surroundings. Maximum/minimum thermometers (Dobbie Brothers) were located at a height of 1.5 m above the ground, facing south, and attached to a wooden post with a horizontal and vertical shield to provide protection against direct sunlight. Thermograph records were obtained with Casella Thermo-hygrographs (Model 931) which were resting on bare ground. A white-painted louvred screen box with no bottom rested on top of the thermo-hygrographs thus providing protection against rain and snow. Casella grass minimum thermometers were used to record minimum ground temperatures.

Intercomparison tests were carried out on all the maximum/minimum thermometers and thermo-hygrographs before starting the project. Results showed that all instruments agreed to within their specification of 1° C. Similar tests were not performed on the grass minimum thermometers since their accuracy (0.2° C) far exceeded our ability to find similar microenvironment with which to test for consistency.

Despite the radiation shields, some direct solar radiation still reached the maximum/minimum thermometers during the daytime. This process gave readings for the daytime maximum air temperature that were too high. Maximum air temperatures were also available from the thermo-

hygrograph record, although problems with the ink supply made the records more sporadic than the daily observations of the maximum/minimum thermometers. To solve the problem a monthly correction figure was obtained by comparing the mean maximum temperature from the thermo-hygrograph records with simultaneous thermometer observations. This technique gave 12 data points for the year at each of the six stations. These data formed the basis of six regression relations which were applied to correct the more complete monthly average temperature data obtained by the thermometers. In general the technique gave satisfactory results, as shown by the Sandy Bay station which exhibited an average monthly temperature departure of -0.4° C when compared to the readings from the Bureau of Meteorology office in Hobart. Such departure can be expected between an inner city recording station and a suburban station.

RESULTS

Initially, regressions of monthly temperature (maximum and minimum) versus height were obtained for each month. However, the lapse rates, defined as the slope of the regression relation, were not found to be statistically significant on a monthly basis. As a result all monthly data were pooled to give single relationships for maximum, minimum and grass minimum temperatures. These had the form:

(a) Maximum Temperature

$$\overline{T}_{max} = 11.05 + \Delta\overline{T}_{max} - 0.00751\ H \quad (1)$$

$R^2 = 97.8\%$

Std error in $\overline{T}_{max} = 0.79°\,C$

(b) Minimum Temperature

$$\overline{T}_{min} = 4.10 + \Delta\overline{T}_{min} - 0.00503\ H \quad (2)$$

$R^2 = 97.5\%$

Std error in $\overline{T}_{min} = 0.55°\,C$

(c) Grass Minimum Temperature

$$\overline{T}_{G\,min} = 0.436 + \Delta\overline{T}_{G\,min} - 0.00463\ H \quad (3)$$

$R^2 = 87.5\%$

Std error in $\overline{T}_{G\,min} = 1.17°\,C$

where $\overline{T}_{max}$, $\overline{T}_{min}$, $\overline{T}_{G\,min}$ = monthly averages of maximum, minimum and grass minimum temperature respectively (° C),

$\Delta\overline{T}_{max}$, $\Delta\overline{T}_{min}$, $\Delta\overline{T}_{G\,max}$ = difference between the monthly average maximum (minimum, grass minimum) temperatures and their respective July value (see table 2)(° C),

and H = altitude (m above sea level).

It may be seen from equations 1 and 2 that the lapse rates for maximum and minimum temperatures are 0.75° C/100 m and 0.5/100 m respectively. Averaging these two values gives an approximation for the lapse rate of the daily mean temperature of 0.63° / 100 m.

The regression pattern for grass minimum temperature reveals temperatures 3 to 5° C cooler than the minimum temperatures for 1.5 m height at the same height. This is consistent with other studies that show a distinctive colder layer close to the ground during night-time cooling (Nunez & Sander 1981; Bacock *et al.* 1977; Bootsma 1976).

The regression only explains 87.5% of the variance which is significantly lower than the equivalent figure for the regression of the minimum temperatures (97.5%). This feature, along with a higher standard error of prediction, points to the marked microscale variability in grass minimum temperatures. Features such as ground type, soil moisture and cold air drainage all accentuate ground temperature differences which in some instances mask the environmental lapse rate.

The suitability of equations 1 and 2 for representing regional lapse rates can be tested using temperature residuals. For each month it is possible to define a mean residual $\overline{Y}_{max}$:

$$\overline{Y}_{max} = \sum_{i=1}^{N} (T_i - T_{meas})/N \quad (4)$$

where T_i = estimate of mean maximum (minimum) temperature from equations 1(2) (° C),

T_{meas} = measured mean maximum (minimum) temperature at station i (° C),

N = number of stations in Tasmania used in the analysis (N = 30).

Residuals were calculated for the period April 1978 to March 1979, which corresponds in time with the data obtained for the Mt Wellington regression. Table 3 shows monthly estimates of g for maximum and minimum temperatures. The standard deviation

TABLE 1

Site Characteristics

Site Name	Terrain	Slope	Aspect	Elevation (a.s.l.)
Sandy Bay	suburban lawn	flat	—	10 m
Strickland Avenue	suburban lawn	slope	N	180 m
Pillinger Drive	suburban lawn	slope	N	440 m
The Springs	grass & bare soil	flat	—	700 m
The Chalet	subalpine forest & scrub	slope	NE	990 m
Summit	dolerite rock & bare soil	flat	—	1 260 m

TABLE 2

Differences Between Monthly Average Maximum (Minimum) Temperatures and Their Respective July Value.

For any month i the value of $\Delta\overline{T}_i$ is given as $\Delta\overline{T}_i = \overline{T}_i - T_7$. $\overline{T}_i$ is the average temperature for the six stations in month i. T_7 is the corresponding value for July.

	J	F	M	A	M	J	J	A	S	O	N	D
$\overline{T}_{max}$ (°C)	13.1	11.5	9.1	5.7	3.5	0.9	0.0	1.1	4.6	7.0	7.9	8.4
$\overline{T}_{min}$ (°C)	7.8	7.9	6.4	4.7	4.3	1.7	0.0	0.3	2.4	3.7	4.9	5.7

TABLE 3

Mean Monthly Residuals ($\overline{Y}$) Formed as the Differences Between the Mt Wellington Lapse Rates (Equations 1 and 2) and Measured Temperatures for 30 Stations in Tasmania, and Standard Deviations (σ) of the Difference.

	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	
T_{max}	-1.04	-1.26	-0.48	-0.47	-0.14	0.06	0.48	-0.36	-0.59	-0.26	-0.97	-0.92	$\overline{Y}$
	1.06	0.61	1.04	0.76	0.75	0.67	1.17	1.17	1.18	1.61	1.69	0.90	σ
T_{min}	1.17	0.99	2.10	1.19	0.60	0.90	0.72	0.38	-0.07	0.67	0.06	-0.33	$\overline{Y}$
	1.20	1.26	1.56	1.48	1.07	1.24	0.88	0.80	0.73	1.58	1.08	1.38	σ

(σ) of the difference is also shown. On a monthly basis, the temperature measurement error of 1° C reduces to just over 0.2° C, which is a figure lower than most of the residuals shown in the table. This treatment naturally assumes a random error in the temperature measurement.

The results shown in table 3 reflect the effect of continentality in Tasmania. Residuals in maximum temperature are mostly negative as most inland stations would be warmer than the equivalent temperatures on Mt Wellington. As expected the residual values become more pronounced in late summer and autumn, and are slightly positive in winter. The standard deviations are also largest in summer since thermal circulation processes such as sea breezes and anabatic winds would be acting then, thus bringing a degree of spatial inhomogeneity to the area.

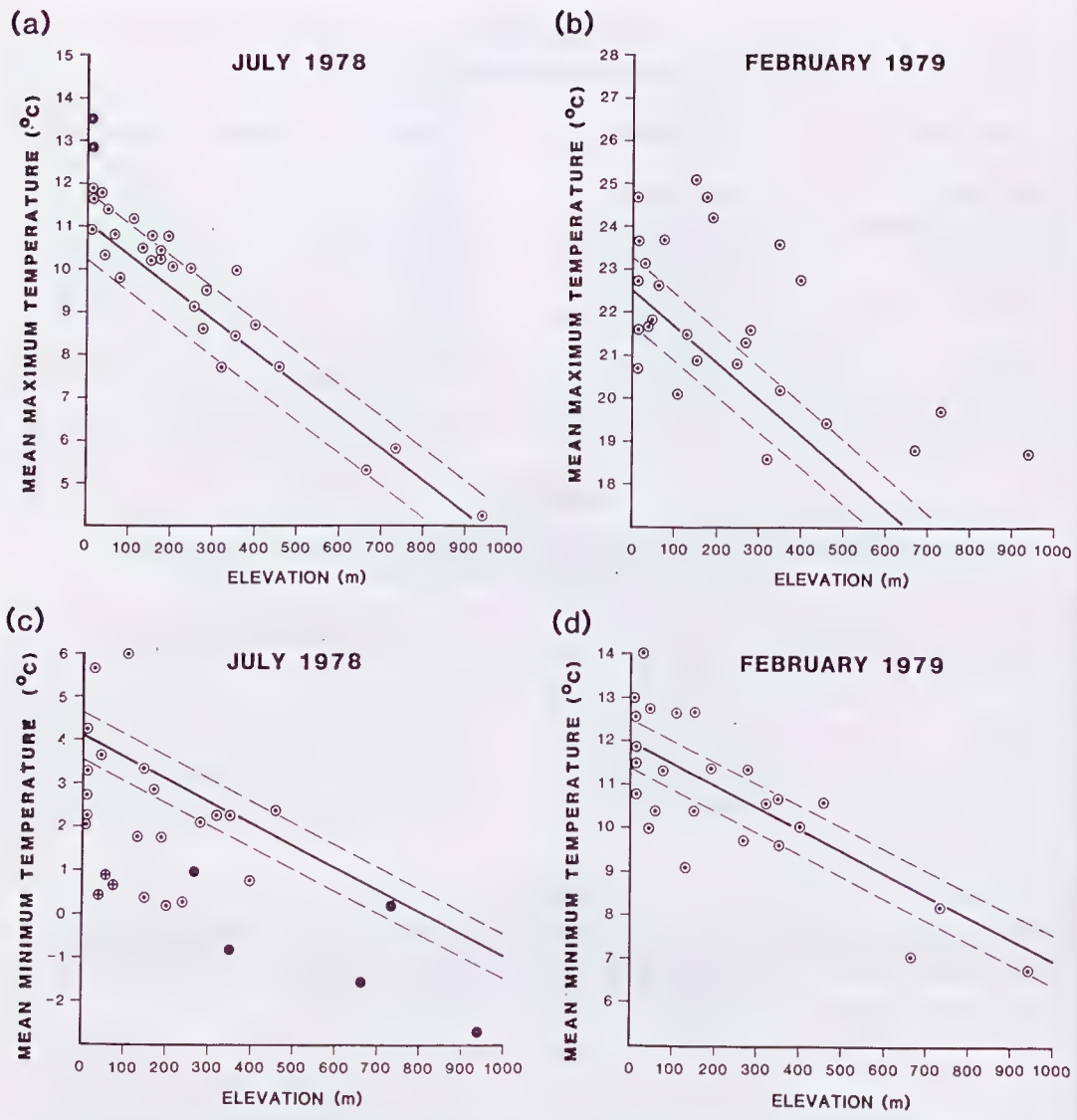

FIG.1 — Plot of mean maximum (minimum) air temperature versus elevation for 30 stations in Tasmania. The Mt Wellington temperatures are represented by the solid lines. The dashed lines represent the range of their standard error.

The residuals in minimum temperature become most positive in winter, again reflecting the effect of continentality. Standard deviations are quite varied with a notable peak in mid-winter (June, July) and in January, and lower values in spring and early summer (October-December). Localized cooling effects such as cold air drainage and cold air ponding are most pronounced in winter, although these effects act to a lesser degree throughout the year.

Figure 1 shows the regional lapse rates for the two extreme months, February and July. Also shown is the regression line from the Mt Wellington data, with the dashed lines denoting the range of the standard error. Approximately 66% of the maximum temperatures in July fall within the standard error bars. The two extreme deviations shown as black circles in figure 1a, represent the east coast stations of Orford (12.9° C) and St Helens (13.5° C). Very little pattern appears in the

February maxima. The regression relation substantially underpredicts the minima on the north and east coasts, and in the midlands area of Tasmania. Approximately 83% of the July minima are below the regression line, with extreme departures being reported on the Central Plateau and western highlands (black circles) and southeast (crosses). These low values in the southeast are probably due to the result of katabatic channelling of cold winds. Substantial improvement occurs in the February minimum temperatures, as 36% of the data points fall within the standard error bars. This indicates that "anomalies" of minima due to high altitude effects or cold air drainage are much less likely to occur in summer than in winter.

DISCUSSION AND CONCLUSION

It is evident from the above results that temperature lapse rates are site specific. On a microscale such factors as slope, aspect, sky view factor, ground characteristics, etc. will affect both the maximum and minimum temperatures. As a result there will be some variability in lapse rates at specific mountain sites such as Mt Wellington (equations 1-3).

At a regional scale other processes (sea breezes, katabatic and anabatic winds, etc.) dominate the variability in temperatures and regional lapse rates. The results presented here show that the Mt Wellington lapse rates do not agree with regional lapse rates for a substantial part of the year. Agreement is best during the time of year when the continental effect is minimized. This condition would occur with maximum temperatures in winter and minimum temperatures in summer. Unfortunately the temperature extremes are the important variables in climate analysis. Similarly, ecological studies use maximum temperatures in summer as a surrogate for climate control on plant growth (Kirkpatrick, pers. comm.). In addition, geomorphic processes are enhanced strongly as thresholds are crossed; for example, freeze-thaw action, which is much more likely with extreme than with average values.

Based on this study it would seem that lapse rates should be studied for specific sites or mountain ranges. It remains to be ascertained if different mountain ranges have the same lapse rates even if their *base* temperatures differ. Clearly it is not possible to assign a single lapse rate applicable throughout Tasmania since regional effects dominate and should cause differences. Botanical studies that investigate ecological zonation with altitude and palynological studies that infer vegetation history and palaeoclimate should recognize the regional nature of the climatic environment of their study area. A proper assessment of temperature change with height should involve firstly a delineation of the climatic region boundaries. Only a lapse rate derived from data collected within these boundaries would be relevant.

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(accepted May 23, 1986)

TWO NEW SPECIES OF GENUS *EPACRIS* (EPACRIDACEAE) FROM TASMANIA

by R.K. Crowden

(with one text-figure)

CROWDEN, R.K., 1986 (12:ix): Two new species of genus *Epacris* (Epacridaceae) from Tasmania. *Pap. Proc. R. Soc. Tasm.* 120: 17–19. ISSN 0080-4703. Botany Department, University of Tasmania, Hobart, Australia 7000.

Epacris apsleyensis R.K. Crowden, sp.nov. and *Epacris grandis* R.K. Crowden, sp.nov. are described. Notes on the distribution, habitat and affinities of both species are included.
Key Words: Epacris, Epacridaceae, Tasmania.

INTRODUCTION

Two new endemic species of the genus *Epacris* from the east coast region of Tasmania have been discovered and are described below. They are illustrated in figure 1.

EPACRIS APSLEYENSIS R.K. CROWDEN, SP.NOV.

Frutex erectus usque ad 1.5 m, plerumque minus quam 1 m. Folia lanceolata vel elliptice lanceolata, 5-9 mm longa, 2-3 mm lata, in supera parte reflexa, apice acuto, breviter mucronato, costa carinata. Flores albi, subsessiles, pro parte majore ad extremitates ramulorum aggregati. Bracteae ovatae glabrae. Sepala ovato-lanceolata, apice acuto. Tubus corollae campanulatus, 2-3 mm longus, glaber. Antherae minus quam 1 mm longae, subsessiles. Stylus quam tubus brevior, prope centrum bulbosus. *Holotypus* Rosedale Rd, at Apsley River crossing, near Bicheno, Tasmania; *Crowden 8404-01*, 23.iv.1984; (HO 95100).

An erect sparsely branched shrub, sometimes reaching 1.5 m in height but mostly less than 1 m. Young stems smooth, red-brown, with sparse to dense hairs. Leaves alternate, spreading and scattered on older branches, 5-9 mm long, 2-3 mm wide; petiole short (ca. 1 mm) semi-appressed to stem, both surfaces concave, the upper surface pubescent with sparse hairs extending onto the base of the lamina, lower surface glabrous; lamina jointed with petiole, lanceolate-elliptic, reflexed in upper part, upper surface glabrescent, lower surface glabrous, apex acute, tip a short mucro, barely pungent, base obtuse, margin scabrous, midrib keeled and conspicuous, other veins indistinct.

Flowers white, erect, sub-sessile, solitary in leaf axils, mostly clustered towards branch tips, but with a tendency to spread down branches in compact leafy spikes; bracts white, streaked with pink, ovate, glabrous, slightly keeled near tip, apex acute, margin ciliolate near tip; sepals white, streaked with pink, ovate-lanceolate, 3-4 mm long, apex acuminate, margin ciliolate near tip. Corolla tube white, +/–campanulate, 2-3 mm long, ca. 3 mm wide at throat, glabrous; lobes geniculate near tube, the distal segments flat or slightly wavy, 3-4 mm long, 2-3 mm wide overlapping at joints, apex obtuse. Anthers brown, less than 1 mm long, enclosed within the corolla tube or tips barely reaching the plane of joints, sub-sessile on short free filament segments. Ovary rounded, smooth, glabrous, 5-locular. Style ca. 1.0-1.5 mm long, usually slightly bulbous near centre, glabrous; stigma clavate, below base of anthers. Nectary scales triangular, apices truncate, ca. 1/3 length of ovary.

Distribution and Ecology

Epacris apsleyensis has a restricted distribution. It is known only from two locations, both of which are adjacent to the Apsley River. It occurs on old river terrace sediments over dolerite bedrock in dry sclerophyll communities (low, open forest), dominated by *Eucalyptus amygdalina* and with a relatively dense understorey including *Callitris oblonga, Banksia marginata* and *Helichrysum costatifructum*.

Specimens Examined (all in HO)

Rosedale Rd, near Bicheno, *Crowden 8307-03*, 10.vii.1983. Apsley River bridge on Rosedale Rd, near Bicheno, *Crowden 8404-01*, 23.iv.1984. Apsley River floodplain at Lilla Villa, *Crowden 8509-07*, 10.ix.1985.

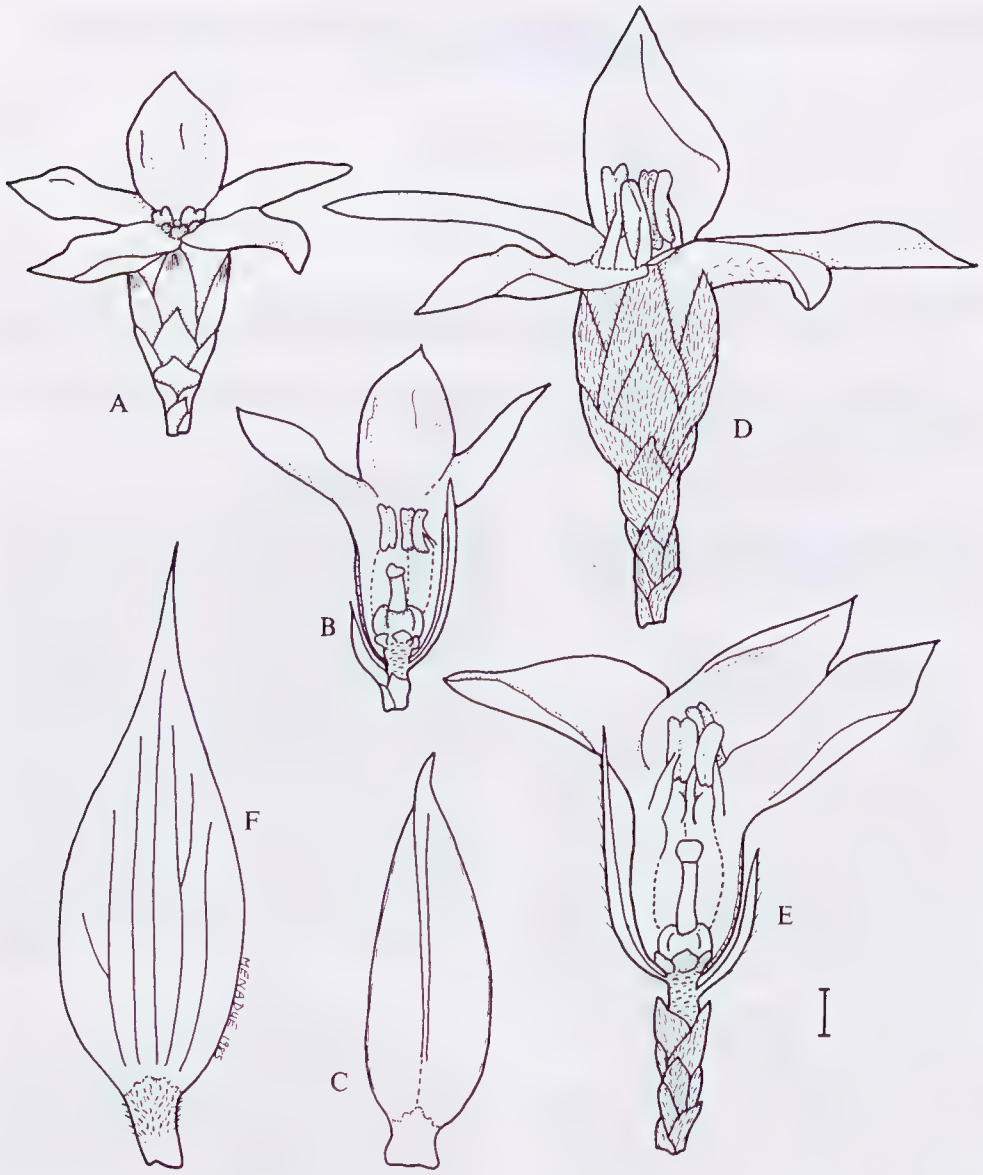

FIG.1 — Epacris apsleyensis*: a — whole flower, b —half flower, c — leaf (abaxial view).* E. grandis*: d — whole flower, e — half flower, f — leaf (abaxial view). Scale bar = 1 mm.*

Comments

Epacris apsleyensis may be confused with *E. tasmanica* W.M. Curtis, which occurs extensively in lowland areas south of the Apsley River and in the Apsley River gorge. It differs from *E. tasmanica* mainly in floral morphology, having anthers enclosed within the corolla tube and a short style (both exserted beyond the tube in *E. tasmanica*), and in the smaller size of the flowers. *E. apsleyensis* flowers throughout winter. The epithet "apsleyensis" refers to its locality.

EPACRIS GRANDIS R.K. CROWDEN, SP.NOV.

Frutex erectus saepe 2 m excedens. Folia lanceolata vel late lanceolata, 10-15 mm longa, 3-4 mm lata; lamina plana vel parum prope basin concava apice acuto, aristato. Flores albi, pedicellati, numerosi, in spicis longis. Bracteae ovatae, pubescentes. Sepala lanceolata, hirsuta, apicibus acutis. Tubus corollae campanulatus, 4-5 mm longus, pilis sparsis extra ad paginam inferam loborum extensis. Antherae magnae, 1.5 mm longae, exsertae. Stylus quam brevior tubus, prope basin parum bulbosus. *Holotypus*, headwaters of Blindburn Creek, near Bicheno, Tasmania *R.K. Crowden 8411-07*, 16.xi.1984 (HO 95101); isotypes AD, CANB, MEL, NSW.

An erect shrub up to 2.5 m in height. Young stems smooth, red to red-browm, pubescent. Leaves alternate, spreading and evenly spaced on older parts of the stem, 10-15 mm long, 3-4 mm wide; petiole short, 1-2 mm long, semi-appressed to stem, upper surface concave, glabrescent, lower surface concave and glabrous; lamina lanceolate to broadly lanceolate, +/–jointed with petiole, flat or slightly concave near base, sometimes with a slightly inflexed tip, both surfaces glabrous, apex acute, tip aristate and pungent, base obtuse, margin slightly scabrous, midrib not keeled (or slightly so near tip), 5 or more veins conspicuous on abaxial surface. Flowers white, erect on distinct pedicel ca. 4 mm long, solitary in leaf axils extending down 1-year branches in long leafy spikes; bracts ovate, hirsute, apex acute, margin ciliate; sepals white, pink streaked, lanceolate, 4-6 mm long, 1-1.5 mm wide, hirsute, apex acute, margin ciliate. Corolla tube +/–campanulate, 4-5 mm long ca. 4 mm wide at throat, white, glabrous internally, sparse hairs on outer surface near throat extending onto undersurface of lobes; lobes geniculate above tube, the distal segments flat, 5-6 mm long, 3-4 mm wide, overlapping at the joints, apex obtuse. Anthers brown, large ca. 1.5 mm long, 0.5 mm wide, exserted beyond plane of jointed lobes on free filament segments ca. 2 mm long. Ovary rounded, smooth, glabrous, 5-locular. Style shorter than the tube, ca. 2 mm long, glabrous, slightly bulbous near base; stigma clavate. Nectary scales triangular with rounded apices ca. 1/3 length of ovary.

Distribution and Ecology

Epacris grandis has been collected from several locations west and northwest of Bicheno. It grows on shallow podzolic soil in dry, stony (dolerite) areas, often with surface water. The community is a dry sclerophyll forest, dominated by *Eucalyptus obliqua*, the understorey including *Banksia marginata, Leptospermum grandiflorum, Bedfordia salicina, Boronia pilosa* and *Xanthorrhea australis*. A small isolated group of plants forms a riverine community on alluvial soil on the lower Douglas River.

Specimens Examined (all in HO)

Summit Nichols Cap, *Moscal 178*, 20.iii.1980; Blindburn Creek, *Moscal 343*, 5.vi.1980; lower reach of Douglas River gorge, *Crowden 8409-20*, 11.ix.1984; headwaters of Blindburn Creek, *Crowden 8411-07*, 16.xi.1984.

Comments

Epacris grandis is an impressive plant, frequently exceeding in height most of the cohabiting understorey species. It flowers in November–December. It appears to be most closely related to *E. marginata* (which occurs on similar exposed dolerite platforms and boulder areas at or near sea-level on Tasman Peninsula and Maria Island), and *E. heteronema*. It is distinguished from *E. marginata* by the vestiture of the bracts, sepals and corolla, and in the more open leaf and inflorescence arrangement. *E. grandis* also lacks the distinctive hyaline leaf margin of *E. marginata*. *E. grandis* resembles *E. heteronema* more closely in its vegetative characteristics, but it is readily separated on floral characters. *E. heteronema* has anthers enclosed within the corolla tube; the bracts, sepals and corolla are glabrous, and the flowers are usually clustered near the tips of the branches. The epithet "grandis" draws attention to the impressive stature of the plant.

ACKNOWLEDGEMENTS

The author acknowledges with thanks, the assistance of Dr A. Orchard with the Latin descriptions, and of Yvonne Menadue for the drawings.

(accepted May 23, 1986)

OBSERVATIONS ON DROUGHT DAMAGE TO SOME NATIVE PLANT SPECIES IN EUCALYPT FORESTS AND WOODLANDS NEAR HOBART, TASMANIA — ERRATA

by J.B. Kirkpatrick and F. Marks

KIRKPATRICK, J.B. & MARKS F., 1986 (12:ix): Observations on drought damage to some native plant species in eucalypt forests and woodlands near Hobart, Tasmania — Errata. *Pap. Proc. R. Soc. Tasm.* 120: 21.ISSN 0080-4703. Department of Geography, University of Tasmania, Hobart, Australia 7000.

In the paper with the above title published in Papers and Proceedings of the Royal Society of Tasmania, Volume 119, 1985, pp. 15–21, two errors were missed in proof-reading. These were p.17, line 3 for "decreases" read "changes", and p.18, line 1 for "5" read "4".

THE HOLOCENE EVOLUTION OF RHEBAN SPIT, TASMANIA

1. Age structure, geomorphic development and sediment characteristics

by G.M. Bowman

(with four tables and five text-figures)

BOWMAN, G.M., 1986 (12:ix): The Holocene evolution of Rheban Spit, Tasmania. 1. Age structure, geomorphic development and sediment characteristics. *Pap. Proc. R. Soc. Tasm.* 120: 23–32. ISSN 0080.4703. C.S.I.R.O. Division of Soils, Private Bag 2, Glen Osmond, South Australia 5064.

Rheban Spit is a small prograded sand barrier located on the east coast of Tasmania in the lee of Maria Island. It consists of four disconformable sets of beach ridges. Shallow drilling at seven sites towards the eastern end of the spit yielded sediment samples for mineralogic and granulometric analyses and detrital shell for radiocarbon dating. The latter indicates that the three oldest sets of ridges were formed about 5 500, 4 200 and 3 100 calendar years ago, while the youngest set is known to have formed this century.

This age structure is unusual for a coastal barrier in eastern Australia because most started to prograde at the end of the Postglacial Marine Transgression (c. 7 000 calendar years ago) and ceased about 2 000 years ago. Rheban Spit has been severely eroded by northeasterly waves during its formation, probably as a result of periods of increased storminess in the Tasman Sea. If the sand isthmus between north and south Maria Island was also removed during these episodes, wave refraction/diffraction and sediment movement patterns near the eastern end of Rheban Spit would have changed significantly and this may account for the disconformable nature of the successive sets of beach ridges which form the spit.

Key Words: Rheban Spit, Tasmania, beach-ridge plain, coastal sand barrier, age structure, sediment characteristics.

INTRODUCTION

The distinctive beach-ridge patterns of Rheban Spit have attracted the attention of a number of coastal geomorphologists (Jennings 1955; Davies 1959, 1961, 1971; Thom *et al.* 1981a). Others have investigated vegetation distribution on the spit (Bowden & Kirkpatrick 1974) and podzol soil development within its sediments (Bowman 1979). The present paper is derived from the latter unpublished thesis, together with the revised radiocarbon data of Thom *et al.* (1981a) and more recent radiocarbon calibration tables, neither of which have been previously used to interpret the evolution of Rheban Spit.

The aim of this paper is to document the age structure of Rheban Spit, to examine the characteristics of the sediments forming the spit and to reconstruct its geomorphic evolution. A complementary paper discusses soil development within Rheban Spit (Bowman in press) using the age framework and sediment data provided here.

Rheban Spit is situated within Mercury Passage on the east coast of Tasmania, about 60 km northeast of Hobart (fig. 1). The Spit is subject to refracted waves approaching from both the north and the south along Mercury Passage but is more exposed to the northerly approach (Jennings 1955). The dual wave approach, combined with the irregularity of the bed of Mercury Passage (fig. 1) and the proximity of Lachlan Island, results in a complex wave refraction/diffraction pattern around the spit.

METHODS

Field Sampling

Large scale aerial photographs were used to examine and map the beach-ridge patterns on Rheban Spit, as well as the disconformable boundaries between the various sets of ridges. This was verified by field examination and was found to be similar to the map of Bowden & Kirkpatrick (1974, fig. 1).

Six sampling sites were located on a transect line previously established across the spit by Bowden & Kirkpatrick. This line intersected four discrete sets of beach ridges (fig. 2) and its use facilitated comparisons with the published soil, vegetation and topographic data. An additional sampling site (Site 2, fig. 2) was established 500 m off the transect line so that the full age range of the most extensive set of beach ridges could be included in the study.

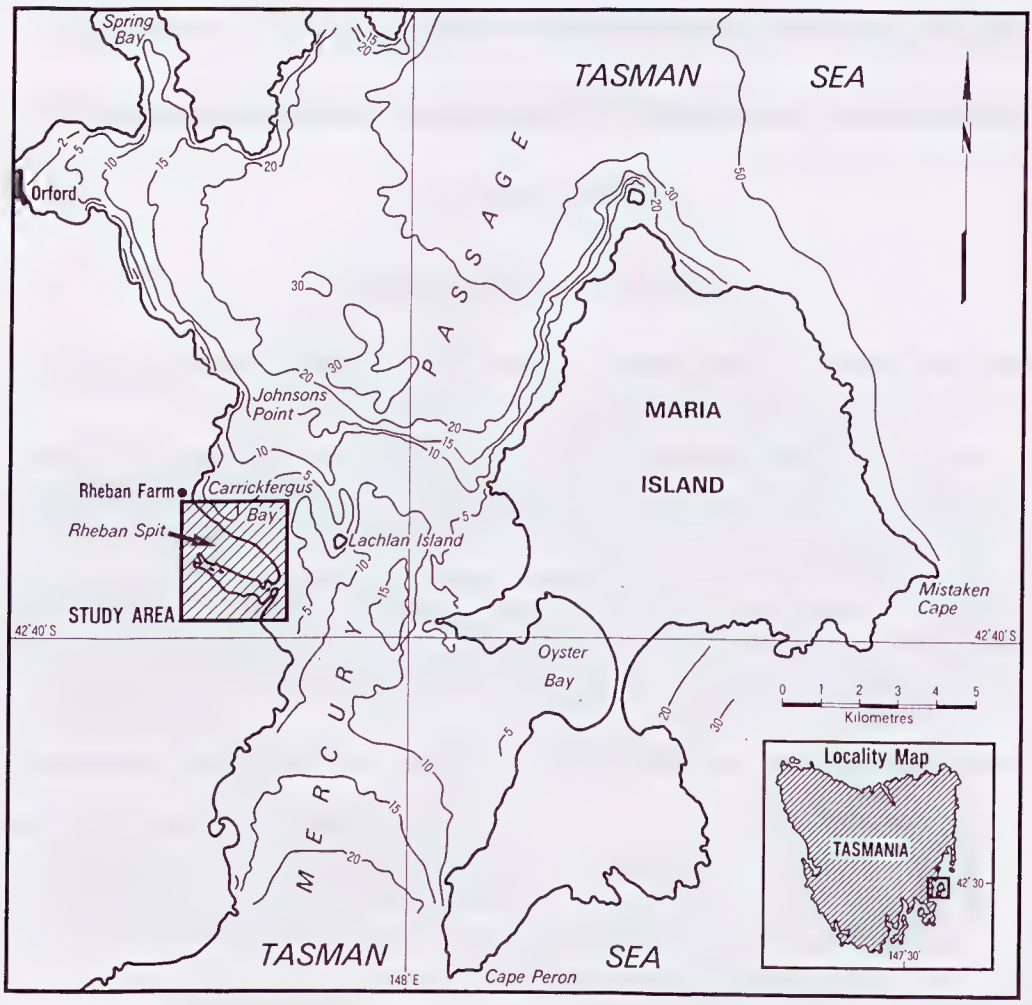

FIG.1 — Location map. Submarine contours in metres.

At each site sediment samples were obtained from pits, then a hand auger was used to sample down to the watertable. Below this level a hand-operated sludge pump yielded samples that were sieved in the field to separate comminuted pieces of shell or wood (.2 mm diameter) for radiocarbon dating (Thom *et al.* 1978).

Radiocarbon Analysis

The use of radiocarbon dating to determine the age structure of coastal barrier deposits in southeastern Australia has been documented by Thom *et al.* (1978, 1981a,b) and a review of other Australian applications of the technique is given in Bowman & Harvey (1986). Radiocarbon dates of shell material incorporated into regressive barrier sediments provide maximum ages for the deposition of those sediments, although systematic studies in several areas of Australia (Thom *et al.* 1978, 1981a,b; Bowman 1979; Bowman & Harvey 1986) have explicitly assumed that the delay between the death of the shell and its incorporation into the barrier sediments was not greater than the statistical error inherent in the radiocarbon age determination. If this assumption is correct for Rheban, the (maximum) ages obtained should closely approximate the true ages of sediment deposition. For a discussion of this problem see Nielson & Roy (1982), Thom *et al.* (1981a) and Thom & Bowman (1982).

Samples were submitted to Geochron Laboratories and the University of Sydney Radiocarbon Laboratory for age determination (GX- and SUA- respectively, table 1). Shell-hash samples were subjected to an HCl surface etch before CO_2 was evolved under vacuum for purification and conversion to benzene. The wood sample (SUA-768/2 was burnt in pure oxygen to produce CO_2. Sample activities were measured with liquid scintillation counters using as the modern reference standard 95% of the ^{14}C activity in 1950 of NBS oxalic acid, normalized to $\delta^{13}C$ = -19.0°/oo with respect to PDB ($d^{14}C$°/oo, table 1). The measured relative ^{14}C activity of each sample was corrected for isotopic fractionation to the base of terrestrial wood ($\delta^{13}C$ = -25.0°/oo w.r.t. PDB; Stuiver & Polach 1977) using the appropriate measured or estimated value of $\delta^{13}C$ as indicated in table 1 (Polach 1976, Thom *et al.* 1978).

Ages were calculated using the Libby half-life of 5568 years and, following the definitions of Thom *et al.* (1981a), the non-reservoir corrected shell dates are referred to as *apparent ages* (yrs b.p.) and the wood date as a *conventional age* (yrs b.p.*). The error terms represent ±1 standard deviation, based on sample, background and standard uncertainties. Subtraction of the revised oceanic reservoir correction for southern Australia of 480 ± 30 yrs (Bowman 1985) yields conventional ages for the shell samples. All conventional ages have been converted to *calibrated ages* (yrs B.P.) using the dendrochronology-based tables of Klein *et al.* (1982). However, rather than express each date as an age range representing a 95% confidence interval (following Klein *et al.* 1982), the mid-point of each age range is quoted in table 1, together with a 2σ error term (which closely approximates the original 95% confidence interval). These calibrated ages relate to the linear calendar time scale (unlike the non-linear radiocarbon time scale) and employ enlarged 2σ error terms to conform with the usual statistical use of confidence levels.

Granulometric and Mineralogic Analyses

Granulometric statistics for each sediment sample were computed by the *method of moments* (modified from Griffiths 1967), the data being obtained by mechanically sieving 100 g oven-dried samples through half-ϕ sieves for 15 minutes and weighing the resulting size fractions to 0.01 or 0.001 g (Griffiths 1967, pp.61-64). None of the samples yielded significant amounts (>0.001 g) of non-organic material finer than 4.00ϕ (i.e. mineral silt or clay).

Mineral composition of the sediment was determined by examining HF-etched, sodium cobaltinitrate-stained grains, previously mounted on glass slides (Bailey & Stevens 1960, Friedman 1971). Quartz, feldspar, heavy minerals, lithics (rock fragments and micas) and shell carbonate were differentiated by binocular microscope. Percentage composition of these components was determined from a count of >1 000 grains per slide, yielding stable and accurate estimates of mineral content (Griffiths & Rosenfeld 1954, Chayes 1956).

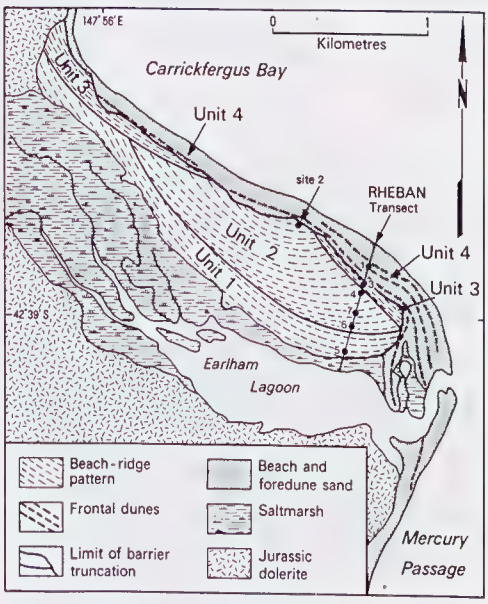

FIG.2 — Map of Rheban Spit showing depositional units and sampling sites.

BARRIER MORPHOLOGY

Rheban Spit is a small sand barrier with an area of 1.83 square kilometres. It is attached to bedrock at its northwestern extremity and is aligned roughly NW-SE (fig. 2). The spit confines Earlham Lagoon and surrounding marshland on its southwestern side and is bordered by Carrickfergus Bay and Mercury Passage on its northwestern and eastern sides, respectively.

Although morphostratigraphically a *prograded bay barrier* of the type described by Thom *et al.* (1978, 1981a), Rheban Spit is unusual in that successive phases of progradation and erosion have resulted in distinctive sets of beach ridges, each with a slightly different orientation and pattern to the preceding sets (fig. 2). Jennings (1955) attributed differences in the orientation of the Spit to varying

TABLE 1
Radiocarbon Age Determinations for Rheban Spit

Site & Lab. Number	Material	$\delta^{13}C$‰ w.r.t. PDB	$d^{14}C$‰ w.r.t. 0.95 NBS ox.	$D^{14}C$‰ w.r.t. 0.95 NBS ox.	Apparent Age yrs b.p.±1σ	Conventional Age yrs b.p.*±1σ	Calibrated Age yrs BP±2σ
R-2 GX4020	Shell hash	+1.2	−354.6±11.9	−388.4±11.3	3950±150	3470±150	3810±320
R-3 GX4021	Shell hash	0.0	−314.5±11.8	−348.7±11.3	3445±140	2965±140	3140±370
R-3 SUA768/1	Shell hash	#+1.0±1.0	−384.8±9.3	−416.8±8.9	4330±125	3850±130	4310±420
R-3 SUA768/2	Wood	#−25.0±2.0	−96.6±13.3	−96.6±13.3	N.A.	815±125	770±150
R-4 GX4363	Shell hash	#+1.0±0.5	−416.4±12.6	−446.7±12.0	4750±180	4270±180	4890±530
R-5 GX4022	Shell hash	+1.3	−445.0±10.1	−483.7±9.6	5310±150	4830±150	5570±270
R-6 GX4364	Shell hash	#+1.0±0.5	−384.5±12.5	−416.5±11.9	4330±170	3850±170	4310±420
R-7 GX4265	Shell hash	#+1.0±0.5	−385.1±9.1	−417.1±8.6	4340±120	3860±120	4330±270

Terminology is explained in the text and conforms with the usage of Thom *et al.* (1981a) except that the revised oceanic reservoir correction of 480 ± 30 years for southern Australian coastal waters.
(Bowman 1985) has been used to calculate the conventional ages. Note also that the enlarged error terms for the calibrated ages represent a 95% confidence interval. GX = Geochron Laboratories; SUA = Sydney University Radiocarbon Laboratory; N.A. = not applicable; # = estimated

exposure to dominant wave approach, but Davies (1959) noted that this does not adequately explain the greater concavity (in plan) of the older beach-ridge sets. Davies suggested that bathymetric changes in Mercury Passage and Carrickfergus Bay caused by a slight fall in sea level were probably responsible for the different patterns. However, during all phases of beach-ridge formation at Rheban accretion appears to have been in a shore-normal direction, rather than shore-parallel. This is apparent from the lack of ridge recurvature (fig. 2) and from a comparison of 1946 and 1966 aerial photographs of the spit, which show the development of the modern foredune ridges (Bowden & Kirkpatrick 1974, fig.1).

The latter study identified three discrete sets of beach ridges, plus the sets of modern foredune ridges. These sets are depicted as progradational Units 1 to 4 in figs 2 and 3. The erosional boundaries between the four units are herein referred to as *truncation limits* after Bowman (1979).

There is some disagreement in the literature as to the overall slope of the surface of Rheban Spit. On the basis of a transect surveyed across the northwestern end, Davies (1961, fig. 6) claimed that the barrier sloped down towards Earlham Lagoon whereas a survey by Bowden & Kirkpatrick (1974) across the southeastern end of the spit showed that it sloped down in the opposite direction towards Carrickfergus Bay (fig. 3). The latter authors maintained that this trend applied along most of the length of the spit, with the exception of the northwestern part surveyed by Davies. However, the two surveys do show that the average elevation of the barrier is approximately 3.5 m above MSL, that in the southeastern section some swales are only one or two metres above MSL, while the frontal dunes rise to over 6 m. Differences in ridge and swale elevations appear to be greatest at the southeastern end of the spit.

AGE STRUCTURE AND GEOMORPHIC DEVELOPMENT

The following reconstruction of the evolution of the regressive (progradational) beach-ridge units at Rheban is based on beach-ridge and truncation limit patterns, radiocarbon age determinations (table 1), and morphological observations by the author and Bowden & Kirkpatrick (1974). Evidence of Pleistocene deposits or Holocene transgressive lithofacies were not found during the fieldwork or the shallow drilling at Rheban.

The initial phase of Holocene barrier progradation at Rheban resulted in a beach-ridge plain which was probably quite extensive: at least as long as the present composite spit, and possibly as wide. The remnant of this initial progradational unit constitutes 25% of the area of the present spit (46.5 ha) and is shown as Unit 1 in figure 2. It consists of a narrow group of comparatively straight beach

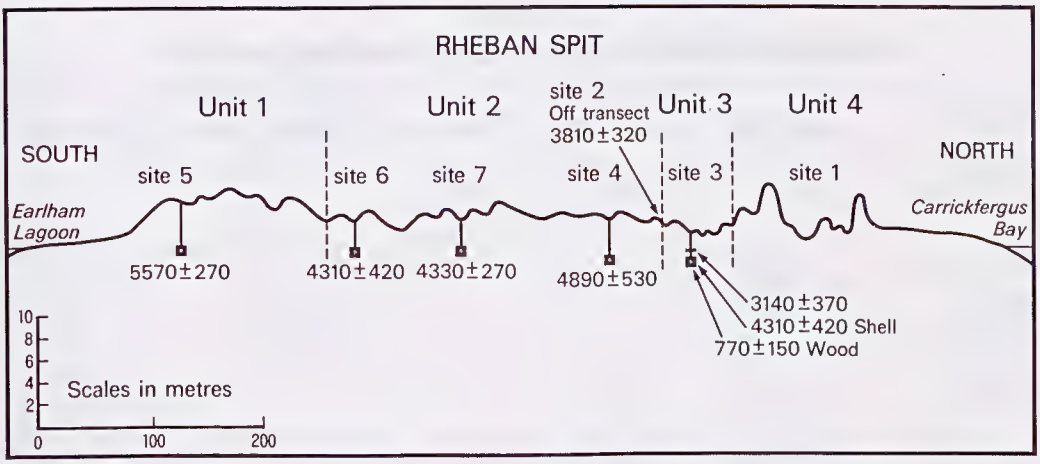

FIG.3 — Cross-section showing position of radiocarbon dated samples and ages in calendar years B.P. (± 2σ).

ridges along the rear of the spit, bordering the northern side of Earlham Lagoon. These ridges are quite distinct at the northwestern end of the spit, where they are obliquely truncated by a later beach-ridge sequence (Unit 3). Along the remainder of the barrier they tend to be less distinctive in plan but are quite distinctive in profile (fig. 3), and the junction with the ridges of Unit 2 is readily discernible.

Only one ^{14}C sampling site was established within progradational Unit 1 (Site 5). Shells from just below MSL at Site 5 were dated at 5 570 ± 270 yrs BP (GX-4022). This is somewhat younger than the initial progradational phase of many other Holocene barriers in eastern Australia (Thom *et al.* 1981a, b), most of which started to prograde soon after sea level stabilized following the Postglacial Marine Transgression, about 7 000 yrs BP.

The beach ridges in Unit 2 are slightly more curved in plan than those of Unit 1, and obliquely abut the latter along their common truncation limit (fig. 2). Radiocarbon dating of incorporated shell also differentiates Unit 2 from Units 1 and 3. Unit 2 comprises a larger proportion of the present spit (34%) than the remnant of any other progradational unit. Because of its width, a large age range was anticipated for the unit and four sites were established within its area, three on the transect line (Sites 6, 7 and 4) and one (Site 2) on the most seaward (youngest) beach ridge (see fig. 2). However, the radiocarbon ages do not support the anticipated age range. Shell hash from Site 6, at the rear of Unit 2, yielded an age of 4 310 ± 420 yrs BP (GX-4364) whilst the sample from Site 2 was dated at 3 810 ± 320 yrs BP (GX-4020), giving an age range of only 500 years for the unit.

The position of Site 4 in relation to the other sites within Unit 2 indicates that the date of 4 890 ± 530 yrs BP (GX-4363) obtained on shell from this site is out of progradational sequence and should be regarded as somewhat "anomalously old" (Thom *et al.* 1978, 1981a). However, application of the z and T statistics (Gillespie 1975, 1982) indicates that this date is not significantly different (at the 0.05 confidence level) from the ages of shell from either Site 6 or 7, although in the latter case the critical values are closely approached (table 2). On the basis of the anomalous age it would seem reasonable to reject the date for Site 4 and to calculate an error-weighted pooled mean age (Polach 1976) for Unit 2 incorporating dates from Sites 6, 7, 2 and 3 (SUA-768/1). The result is a mean age (± 2σ) of 4 180 ± 170 yrs BP. Both this average age for Unit 2 and the date from the progradationally oldest site in Unit 2 (Site 6) are statistically significantly younger (at the 0.001 level) than the 5 570 ± 270 yrs BP date obtained for Unit 1 (z = 8.7 and 5.05, T = 75.9 and 25.5, respectively).

Unit 3 is easily distinguished on air photos by its beach-ridge pattern, which more closely parallels the present shoreline than the ridge patterns of Units 1 and 2. Unit 3 truncates most of the beach ridges in Unit 2, and is itself truncated by the Unit 4 frontal dunes along part of its (former) length (fig. 2). Unit 3 now comprises only 10% of the spit, consisting of a few beach ridges, most of which are

TABLE 2

Statistical Significance Matrix for Radiocarbon Dates from Unit 2

^{14}C age ($\pm 2\sigma$)	Site 6 4310 ± 420	Site 7 330 ± 270	Site 4 4890 ± 530	Site 2 3810 ± 320	Site 3 4310 ± 420
Site 6 4310 ± 420	—	z = 0.08 T = 0.01	z = 1.72 T = 2.94	z = 1.89 T = 3.59	z = 0 T = 0
Site 7 4330 ± 270		—	z = 1.88 T = 3.55	z = 2.48* T = 6.17*	z = 0.08 T = 0.01
Site 4 4890 ± 530			—	z = 3.49* T = 12.17*	z = 1.72 T = 2.94
Site 2 3810 ±320				—	z = 1.89 T = 3.59

Asterisk indicates z and T values statistically significant at 0.05 level and d.f. = 1. With one degree of freedom (where d.f. = n-1) the critical values for the z statistic at the 0.05, 0.01 and 0.001 confidence levels are 1.96, 2.58 and 3.2, respectively. The corresponding critical values for T (with the Chi squared distribution) are 3.84, 6.64 and 10.83.

low in elevation and rather difficult to distinguish on the ground. The northwestern and southeastern remnants of Unit 3 have been tentatively correlated on the basis of their surface morphology, stratigraphic position and orientation. Where the transect line intersects the southeastern segment of Unit 3, a single sampling site was established (Site 3), the elevation of which is only 1.4 m above mean high water level (fig. 3).

Three radiocarbon dates have been obtained on material from Site 3. Shell hash from 1.5 m below the groundsurface (just below MHWL) yielded a date of 3 140 ± 370 yrs BP (GX-4021), while shell hash from 2.5 m was dated at 4 310 ± 420 yrs BP (SUA-768/1). Although significantly different at the 0.1% confidence level (z = 4.18; T = 17.5), the two dates are not mutually inconsistent in terms of their stratigraphic position. Site 3 was located close to the truncation limit between Units 2 and 3 (but definitely within Unit 3, see figs 2 and 3). The date on the upper stratum shells (3 140 ± 370 yrs BP) relates to the initiation of Unit 3, whereas the lower stratum date (4 310 ± 420 yrs BP) is associated with the underlying shell and sediments of Unit 2. The latter date is not significantly different from the dates obtained from Sites 6, 7, 4 and 2 (see table 2) and therefore fits very well within the age structure of Unit 2. For this reason it was incorporated in the calculation of the mean age for Unit 2.

A third date from Site 3 (SUA-768/2: 770 ± 150 yrs BP) was obtained on wood fragments separated from the shell hash used to yield SUA-768/1. However, this anomalously young date relates to dead *in situ* tree roots and not to wood debris deposited with the sediments.

The fourth progradational unit at Rheban consists of a set of frontal dunes which are parallel to the present shoreline and comprise about 23% of the present Spit. Bowden & Kirkpatrick (1974) compared 1946 and 1966 aerial photographs of Rheban and concluded that during this period the spit had accreted considerably at the southern end and that some erosion had occurred near the northern end. They found that two frontal dunes had formed near the southern end since 1946 AD and that the older frontal dunes were undifferentiated from them. As all the frontal dunes are still subject to active sand movememt to some degree, Unit 4 has been assigned a geomorphic age of zero years (Bowman 1979).

SEDIMENT CHARACTERISTICS

Results of the granulometric analyses indicate that the sediment forming Rheban Spit is very well sorted, fine to medium sand (Krumbein 1938), with an overall mean grain size (all samples) of 2.14ϕ (0.23 mm) and a standard deviation of 0.10ϕ. The homogeneity of the sediment is apparent from table 3, in which the pooled mean grain size and sorting coefficients (standard deviations) of three lower samples from each site are compared. Sites 2 to 7 (from progradational Units 1, 2 and 3) differ

TABLE 3

Granulometry of Selected Rheban Sediment Samples

Progradational Unit	Approx. Age (yrs)	Sampling Site	Mean Grain Size ($x\phi$)	Coefficient of Sorting ($\sigma\phi$)
1	5500	5	2.02	0.16
2	4200	6	2.08	0.18
2	4200	7	2.15	0.17
2	4200	4	2.19	0.16
2	4200	2	2.15	0.19
3	3100	3	2.11	0.21
4	0	1	2.34	0.17

little in terms of their mean grain size or sorting coefficients and these differences are not statistically significant at the 5% confidence level (z = 1.39 max.).

A plot of mean grain size against standard deviation (sorting) is given in figure 4 for *all* Rheban sediment samples, except those near-surface samples which contained organic matter. This indicates that the sediment characteristics of progradational Units 1, 2 and 3 are very similar with the distribution fields overlapping, but that the Unit 4 samples form a discrete cluster near the top of the diagram. A general decrease in grain size (increase in $x\phi$) and a slight improvement in sorting (decrease in$\sigma\phi$) are evident if the progradational units are compared in order of decreasing age (Units 1, 2, 3 and 4 respectively).

The contrast between the Site 1 (Unit 4) sediments and those from the other Rheban sites is also reflected in the mineralogical composition. The percentage composition of quartz, feldspar, heavy minerals, lithics and shell carbonate for the deepest samples from each site are given in table 4. Variations between Sites 2 to 7 are slight, but the Site 1 quartz percentage is markedly lower than for the other sites, with the corollary that the proportions of feldspar, heavy minerals and shell carbonate are higher. The content of lithics does not appear to vary between the sites, but the resolution of the data precludes a definitive statement (Griffiths 1967).

DISCUSSION

In several respects Rheban Spit differs from other Holocene sand barriers in southeastern Australia. Whereas other prograded beach-ridge plains are composed of conformable ridges which are usually subparallel to each other and display little evidence of truncation or depositional hiatuses (Thom *et al.* 1978, 1981a), Rheban consists of

TABLE 4

Mineralogy of Selected Rheban Sand Samples

Progradational Unit	Approx. Age (yrs)	Sampling Site	Quartz %	Feldspar %	Heavy Minerals %	Lithics %	Shell Carbonate %
1	5500	5	96.8	2.0	1.1	0.1	—
2	4200	6	96.4	2.7	0.9	—	—
2	4200	7	96.5	2.5	1.0	0.1	—
2	4200	4	96.0	3.1	1.0	—	—
2	4200	2	97.4	2.0	0.2	0.4	—
3	3100	3	95.6	2.7	1.5	—	0.2
4	0	1	90.8	4.1	3.5	0.1	1.5

discrete sets of beach ridges, each of which is disconformable with the other sets. Morphological studies of Holocene barriers on other parts of the Australian coast indicate that conformable beach-ridge patterns predominate, although disconformable sets of beach ridges (as opposed to cheniers) have been reported from Western Australia (Shepherd 1981) and the Gulf of Carpentaria (Smart 1976).

Another point of contrast between Rheban Spit and other east Australian barriers is the delay that occured at Rheban between the termination of the Postglacial Marine Transgression and the initiation of regressive sedimentation. Many Australian barrier studies have shown that progradation of regressive lithofacies soon followed the stabilization of the sea at approximately its present level (Thom *et al.* 1978, 1981a, b; Bowman & Harvey 1986). In the majority of documented cases this sediment flux was rapid and prolonged and resulted from an equilibrium adjustment of the nearshore/ onshore profile to the large quantities of sediment that had been swept up from the continental shelf by the transgressive sea (Thom 1984, Thom & Roy 1985).

Several alternative explanations could account for the apparent delay in progradation at Rheban. Firstly, it is possible that sedimentation did commence immediately after the Postglacial Marine Transgression but that this deposit was subsequently completely removed by erosion. Alternatively, deposition did not take place at Rheban prior to the formation of depositional Unit 1, and the time lag was caused by a lack of sediment accompanying the transgressing sea. This explanation would probably require the floor of Mercury Passage to have had only a minimal sediment cover during times of glacial low sea level. It is possible that the transgressing sea did bring sediment with it, but that it was initially deposited at locations other than Rheban. Given the present relative abundance of sediment around the shores of Mercury Passage this proposition would appear to be feasible. The uniform granulometry and mineralogy of the Rheban sediments indicate that they have been intensively reworked and are of "marine" origin (Roy *et al.* 1980). The slight but consistent granulometric trends apparent across the depositional units also suggest the repeated reworking of a limited reservoir of sediment.

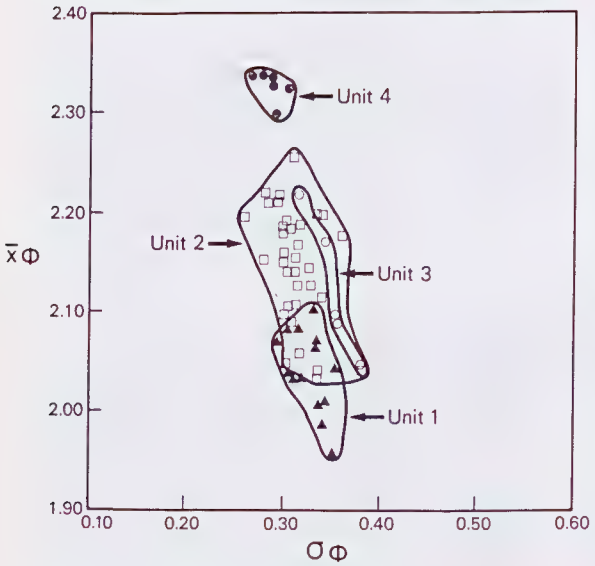

FIG.4 — Plot of mean grain size (± σ) against sorting coefficient (σφ) for selected sediment samples from the four progradational units comprising Rheban Spit.

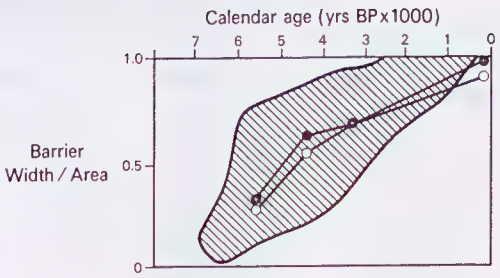

FIG. 5 — Plot against age of proportional barrier width along the cross-section (solid circles) and proportional barrier area (open circles) for progradational units at Rheban Spit. Shaded area encompasses range of barrier width: age values in Thom et al. *(1981b).*

Apart from the delayed start of progradation at Rheban, the sedimentation trends illustrated in figure 5 resemble those of the majority of prograded Holocene barriers reported in Thom *et al.* 1981b, fig. 2), where rapid progradation was followed by progressively slower rates as the initial sediment supply dwindled and was not augmented by fluvial sources or alongshore transport. However, one contrast is apparent: progradation continued until more recently at Rheban than at any of the New South Wales barriers, presumably because of erosion and redeposition of sediment within the littoral compartment (Thom *et al.* 1981b, p.324).

As discrete sets of beach ridges were not identified in the New South Wales barriers, it is not possible to make direct comparisons with progradational events at Rheban. However, the morphology and age structure of the sets of beach ridges at Rheban indicate that progradation was definitely episodic at this locality, that the episodes of sedimentation were temporally discrete, and that they were separated by periods of shoreline erosion. The latter were presumably caused by intense storminess and/or changes in the direction of wave approach, although less likely factors such as tectonic instability cannot be totally excluded. Although the general applicability of these results is not clear, they do represent an advance on the New South Wales studies which were not able to resolve problems associated with episodicity of progradation (Thom *et al.* 1981a, pp.29-30).

It is possible that the initiation of Rheban Spit was linked to the formation of a sand isthmus between north and south Maria Island (fig. 1). Although no information is available on the age structure of this deposit, a reconnaissance survey indicated that the sands forming the small barrier contiguous with the northern end of the isthmus were moderately-well podzolized, whereas the isthmus proper appeared to be free of soil development. It was also noted that the isthmus was subject to severe wave attack on the eastern side; also, evidence of aeolian reworking and washover deposition was abundant. From these observations it was deduced that at least part of the deposit between north and south Maria Island is probably as old as Rheban Spit (i.e. mid-Holocene), but that the narrow and relatively low isthmus has been substantially reworked by wind and wave activity, and could have been completely removed during periods of intense storminess in the Tasman Sea (Thom 1974).

The hiatuses between the depositional units forming Rheban Spit probably reflect three major erosional episodes during which dominant north-easterly storm waves substantially eroded the Carrickfergus Bay shoreline. It is postulated that the subsequent temporary presence of a passage between north and south Maria Island would have significantly influenced wave refraction/diffraction patterns near the eastern end of Rheban Spit. The resulting alteration in sediment deposition patterns might account for the differing orientations and patterns of the Rheban beach ridges.

On the basis of the age structure presented above, the ages of the inferred erosional phases can only be approximated as 5 500-4 200, 4 200-3 100, and <3 100 years BP. Additional dating would more clearly define the age limits of the depositional units at Rheban and might reduce the age ranges for the inferred erosional periods. Drilling and dating of the Maria Island isthmus would probably indicate whether this feature has been instrumental in the formation of Rheban Spit.

The ability to distinguish depositional units within beach-ridge plains by their surface morphology has implications for determining the age structure of such coastal deposits. Where this distinction can be made, radiocarbon dating can be more effectively used to determine an age (or age range) for each depositional unit rather than using dates to differentiate units on a purely statistical basis. Further, as the areal extent of individual depositional units can be measured where they are delineated by surface morphology, it is also possible to calculate the area of sediment accreted during specific time intervals. This is an improvement on the use of "dimensionless barrier width" measured along a single (or at best a few) transect lines (Thom *et al.* 1981a) but is still inferior to actual sediment volumes calculated from detailed stratigraphic and dating information (e.g. Harvey & Bowman in press).

CONCLUSIONS

Rheban Spit is composed of discrete sets of beach ridges which are not mutually conformable in section or plan. Each series of ridges is bound by truncation limits which represent periods of marine erosion, rather than simply periods of non-deposition of sediment. The age structure of the sediments, as determined by radiocarbon dating of detrital shell, shows that discrete sets of beach ridges were deposited approximately 5 500, 4 200 and 3 100 calendar years ago, with another set forming during this century. Reasons for the alternation between erosional and depositional phases are not known, but changes in the beach-ridge patterns could be associated with periodical removal of the isthmus between north and south Maria Island.

ACKNOWLEDGEMENTS

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(accepted April 18, 1986)

TETRATHECA GUNNII HOOK. F. ON SERPENTINE SOILS NEAR BEACONSFIELD, TASMANIA

by M.J. Brown, H.J. Bayly-Stark, F. Duncan and N. Gibson

(with one table and two text-figures)

BROWN, M.J., BAYLY-STARK, H.J., DUNCAN, F. & GIBSON, N., 1986 (12:ix): *Tetratheca gunnii* Hook. f. on serpentine soils near Beaconsfield, Tasmania. *Pap. Proc. R. Soc. Tasm.* 120: 33–38. ISSN 0080-4703. National Parks and Wildlife Service, Sandy Bay, Tasmania 7005.

The rediscovery of *Tetratheca gunnii* Hook. f., a species last collected in 1843 and presumed extinct, is reported. The morphological variability among plants (including previously undescribed fruit) is given to facilitate comparison with descriptions of the type material. The habitat of the species is described and options for management to conserve viable populations are discussed.

Key Words: *Tetratheca gunnii*, serpentine, Tasmania, conservation.

INTRODUCTION

This paper reports the rediscovery of *Tetratheca gunnii* Hook. f., a species previously known only from the type and one duplicate collection made by R. C. Gunn in 1843 (Hooker 1855, in Thompson 1976). In their census of extinct and endangered Australian plants, Leigh *et al.* (1984) categorised *T. gunnii* as "presumed extinct". Leigh *et al.* (loc. cit.) and Thompson (loc. cit.) have emphasized the need to relocate the species, so that its specific status can be verified and appropriate conservation measures can be undertaken.

THE STUDY AREA

The holotype of *T. gunnii* was collected from the foothills of the Asbestos Range on serpentine rocks. The Asbestos Range and associated Dazzler Range form a dissected upland between the Tamar River (Port Dalrymple) and Port Sorell, reaching an altitude of 520 m. The ranges are located in the moist subhumid and humid warm climatic zones respectively (Gentilli 1972). The area is geologically and topographically complex (Gee & Legge 1971) and supports a range of vegetation types from rainforest through eucalypt forest to heath (Brown & Buckney 1983, Kirkpatrick & Dickinson 1984).

The search for *Tetratheca gunnii* was concentrated on the Cambrian serpentinite, peridotite and associated ultramafic rocks which crop out locally in undulating terrain in the eastern foothills of the Dazzler Range, about 3 km west of Beaconsfield (fig. 1). The range of altitudes of these rocks is 20 to 220 m. The vegetation mainly comprises dry

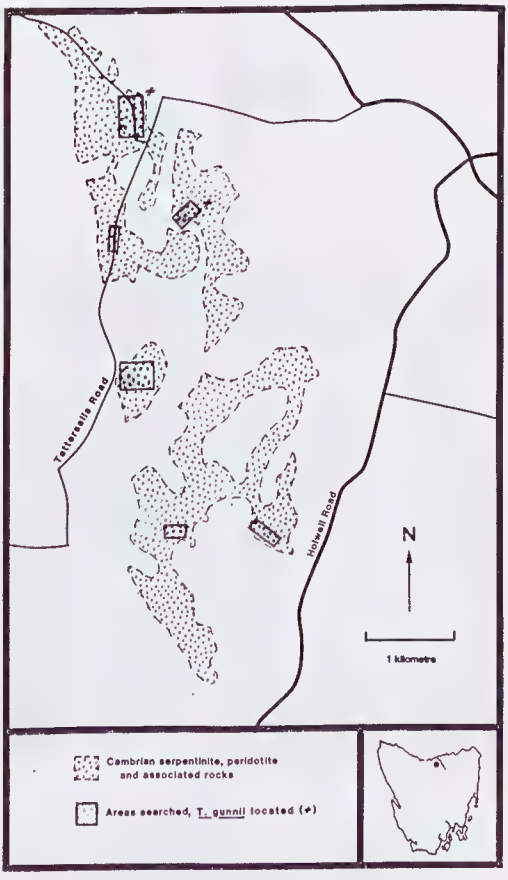

FIG.1 — Map showing distribution of serpentine soils, areas searched and locations of T. gunnii.

FIG.2 — Tetratheca gunnii: *(a) habit of flowering specimen, x0.75; (b) flower with one sepal, one petal and three stamens removed, x7.5; (c) stamens, x15; (d) ovary and style, x15; (e) fruit, x7.5.*

sclerophyll forest with a heathy or shrubby understorey. Shafts, scrapes and spoil heaps are common in the serpentinite area, which was worked previously for asbestos and more recently for chromite. Other land uses in the immediate area are logging for pulp, sawlogs and firewood, grazing, clearing, gravel extraction and protection of water quality (water reserve).

The area was searched by the authors on 3 October 1985 when the initial findings were made. The area was revisited on 19 December 1985 to obtain fruiting material for description and seed for propagation by the Royal Tasmanian Botanical Gardens. Specimens are lodged with the Tasmanian Herbarium (HO).

RESULTS AND DISCUSSION

Occurrence and Habitat

Plants were found growing on shallow soils at four distinct locations in two of the six areas searched (fig. 1). All of the sites were underlain by serpentine rocks (Gee & Legge 1971). A total of 24 individuals were found with 20 in one population, two in another and the remaining two plants occurring as solitary individuals. In each case, the plants were found growing on gently sloping hillsides of east to southeast aspect in heathy *Eucalyptus amygdalina* woodland (Duncan & Brown 1985). *Eucalyptus amygdalina* is the overstorey dominant, with *E. ovata* present as a minor species. *Casuarina littoralis* and *Banksia marginata* form a small tree-tall shrub stratum over a dense heath dominated by *Epacris virgata, Correa reflexa* and *Hibbertia riparia*. Cutting grass (*Gahnia* spp.), grasses, saggs and procumbent shrubs are also widespread. Species lists for each site are given in appendix 1.

At each location, *T. gunnii* is closely associated with two other endemic species, also largely restricted to serpentine rocks, viz. *Epacris virgata* and *Spyridium obcordatum* (Kirkpatrick & Brown 1984). However, the latter two species are much more abundant. Serpentine rocks worldwide are noted for their high local endemicity (e.g. Whittaker 1954, Kruckeberg 1954) and those near Beaconsfield appear to be no exception.

Kruckeberg (1954) presented evidence that serpentine endemics are unable to compete with non-serpentine species in comparatively dense closed communities. The very pronounced boundaries of the *Epacris virgata* population indicate that this species is a serpentine endemic. *Spyridium obcordatum* is strongly associated with serpentine rocks, but does occur albeit rarely, on other rock types (Brown *et al.* 1983) and may represent an example of biotype depletion (Stebbins 1942). *Tetratheca gunnii* has only been found on serpentine rocks and may be a serpentine endemic. It exhibits "serpentomorphic" characteristics (Whittaker 1954) as compared with its close congener *T. pilosa*. The latter species occurs with *T. gunnii* on this rock type but is found more widely in other edaphic situations. The ecological and genecological status of *T. gunnii* can only be confirmed by further investigations.

Description

In most respects, the plants found in the present study fit closely to the description of *T. gunnii* given by Thompson (1976). The absence of an anther tube is particularly distinctive (fig. 2) and immediately separates the species from *T. pilosa* and from the morphologically similar *T. procumbens* Gunn ex Hook. f. (which is included in *T. pilosa* by Thompson *loc. cit.*).

TABLE 1

Morphometric Data for *Tetratheca gunnii*. Mean Value (and ranges) in mm.

	Site	Site 2	Sites 3 and 4				
			P1	P2	P3	P4	Mean
Leaf length (blade)	5.4 (5.2-5.8)	3.5 (3.0-3.8)	5.1 (4.2-5.8)	4.1 (3.8-4.5)	5.2 (4.8-5.8)	4.6 (3.6-5.5)	4.65
Leaf width (max)	1.0 (0.9-1.0)	0.9 (0.7-1.2)	1.1 (0.9-1.2)	1.1 (0.9-1.4)	1.0 (0.9-1.1)	0.9 (0.6-1.1)	1.0
Petal length	3.4 (3.0-4.2)	2.6 (2.2-3.2)	5.2 (4.6-5.7)	4.5 (4.0-5.2)	4.5 (4.0-4.8)	3.5 (3.3-3.9)	4.0
Sepal length	1.0 (1.0-1.0)	0.9 (0.9-1.0)	1.3 (1.2-1.3)	1.0 (1.0-1.1)	1.0 (1.0)	1.1 (1.0-1.1)	1.05
Stamen length	2.1 (2.0-2.2)	1.4 (1.2-1.6)	2.6 (2.5-2.7)	2.4 (2.3-2.4)	2.3 (2.1-2.4)	1.9 (1.8-2.2)	2.1
Peduncle length	3.6 (3.2-4.3)	2.4 (2.1-2.6)	2.3 (1.5-2.7)	2.4 (1.9-2.7)	2.7 (2.4-3.1)	2.3 (2.3)	2.6
Style length	1.6 (1.4-1.8)	1.3 (1.2-1.5)	2.1 (2.0-2.1)	1.9 (1.8-2.0)	2.0 (2.0)	2.0 (1.9-2.0)	1.8
Stem width (internodal in flowering section)	0.6 (0.6)	0.7 (0.7)	0.7 (0.7)	0.6 (0.6)	0.7 (0.7)	0.7 (0.7)	0.7

Plants are generally lax and less than 0.3 m tall, but one individual was erect to 0.8 m. The plants are smaller in all their parts than *T. pilosa* especially in comparison with the robust forms of the latter which grow in the same area. Table 1 gives some morphometric data from six plants of *T. gunnii* to indicate variability between plants.

The petals vary in colour from pale lilac to deep pink-purple. Thompson (*loc. cit.*) suggests that the petals are usually white, but no white flowered specimens were seen. However, flowers on some specimens did fade within a few days of collection.

The fruit is a compressed 2(-3) locular capsule, obovate to cuneate, turgid 4.0 mm long, 2.5-3.0 mm wide, with uniform cover of sparsely scattered gland-tipped hairs. Slightly channelled along septum, style not persistent, opening along margin.

Seeds are pale, 3.0 mm long, almost oblong, covered with fine, appressed to spreading hairs, appendage pale covered with finer hairs. Similar to *T. pilosa* but base not scarred.

Conservation and Management

It seems likely that the serpentine provides the only suitable habitat for *T. gunnii*, and its distribution is very restricted even on this geological type. The serpentine rocks in the area occupy 530 ha, of which 270 ha (51%) is State Forest, 220 ha (41%) is privately owned and 40 ha (8%) is Crown Water Reserve. All of the *T. gunnii* plants found were in State Forest.

The main risks to survival for the species appear to be land clearing, adverse firing and grazing regimes and overcollecting. Some of the private land in the area has been cleared to rough pasture, to the detriment of *Epacris virgata* and *Spyridium obcordatum*, and further clearing for agriculture and for gravel extraction are potential threats. There is good evidence that grazing by introduced stock and frequent firing on State Forest in the area were also detrimental to the above species in the past. There has been a dramatic increase in the abundance and vigour of *E. virgata* on some previously grazed sites following recent cessation of grazing. Duncan (1981) has shown that *Tetratheca glandulosa* (= *T. labillardieri* Thompson) is dependent on seed for regeneration following a hot fire. If the same applies to *T. gunnii*, then fire regimes suitable for the maintenance of the populations will have to be determined.

The serpentine areas on State Forest generally support poor stands of timber, and are unlikely to

be clearfelled. Clearing of tracks for timber, mining or gravel extraction may not pose a direct threat to the species. However there remains the problem of possible introduced pathogens. The effects of *Phytophthora cinnamomi* on serpentine soils in general and *T. gunnii* in particular are unknown. Other species of *Tetratheca* are very susceptible to attack, but no symptoms consistent with *P. cinnamomi* infection were evident in the area. Soils in the area have been tested previously, but no *P. cinnamomi* was recovered.

The occurrence of *T. gunnii* in such close association with other restricted endemic species, confers on the area a very high significance for biological conservation. It is essential that a monitoring programme be established to continually review the status of *T. gunnii*, which has now been confirmed as an extant but endangered species.

ACKNOWLEDGEMENTS

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APPENDIX 1

List of Vascular Species Associated with *Tetratheca gunnii* Hook. F. Near Beaconsfield.

A comprehensive list of species is given below for each *T. gunnii* site. Species were recorded from a circular plot of a nominal 15 m radius, which was centred on each population of *T. gunnii*. Except where indicated, species authorities are those given by Brown *et al.* (1983) for endemics, Curtis (1963, 1967) and Curtis and Morris (1975) for other dicotyledons, and Willis (1970) for other monocotyledons and pteridophytes. Endemic species are prefixed by an 'e', introduced species by an 'i', and poorly reserved species (Brown *et al.* 1983) by an 's'. Abundance of each species on each site is indicated by: + = uncommon; o = occasional; a = abundant and/or dense. The numbers of *T. gunnii* recorded from each site are: site 1 one plant; site 2 — one plant, site 3 — two plants, site 4 — twenty plants.

			SITE			
			1	2	3	4
PTERIDOPHYTES						
Aspleniaceae		*Asplenium flabellifolium*	+			
Dennstaedtiaceae		*Pteridium esculentum*	+	o	+	o
Lindsaeaceae		*Lindsaea linearis*	+			+
Sinopteridaceae		*Cheilanthes tenuifolia*	+			
DICOTYLEDONS						
Asteraceae		*Craspedia glauca*	+			
		Gnaphalium sp.	+			
		Helichrysum dendroideum	+	+		
		Helichrysum scorpioides	+	+	+	+
	i	*Hypochaeris radicata*		+		
		Olearia erubescens			+	
		Olearia lirata	+			
		Olearia ramulosa		+		
Campanulaceae		*Wahlenbergia* sp.	+			+
Casuarinaceae		*Casuarina littoralis*	a	a	a	a
Dilleniaceae		*Hibbertia riparia*	a	a	a	a
Droseraceae		*Drosera auriculata*	+		+	
Epacridaceae		*Acrotriche serrulata*	o	+	+	o
		Astroloma humifusum	a	o	o	o
		Epacris impressa	o	+	o	o
	e,s	*Epacris virgata*	a	a	a	a
		Styphelia adscendens		+	+	
Fabaceae		*Bossiaea prostrata*	o	+	+	
		Hovea heterophylla	+	+		
		Pultenaea stricta				o
Goodeniaceae		*Goodenia lanata*	o	+	+	+
Haloragaceae		*Gonocarpus tetragynus*	o	o	+	o
		Gonocarpus teucrioides		+		
Lauraceae		*Cassytha glabella*	+	+		
		Cassytha pubescens				+
Mimosaceae		*Acacia dealbata*		o		
		Acacia melanoxylon	+			
		Acacia mucronata			+	
		Acacia verticillata		o		
Myrtaceae		*Baeckea ramosissima*			o	o
	e	*Eucalyptus amygdalina*	a	a	a	a
		Eucalyptus ovata	o	o	o	o
		Leptospermum scoparium		+		
Oleaceae		*Notelaea ligustrina*		+		
Oxalidaceae		*Oxalis corniculata*			+	
Pittosporaceae		*Bursaria spinosa*			o	+
Polygalaceae		*Comesperma volubile*	o	+	+	+
Proteaceae		*Banksia marginata*	a	a	a	a
	e	*Hakea epiglottis*				+
	e	*Lomatia tinctoria*	o	o	+	o
Rhamnaceae	e	*Pomaderris elliptica*			a	
		Pomaderris pilifera				+
	e,s	*Spyridium obcordatum*	a	+	o	a

APPENDIX 1

List of Vascular Species Associated with *Tetratheca gunnii* Hook. F. Near Beaconsfield.

			SITE			
			1	2	3	4
Rubiaceae		Galium australe			+	
Rutaceae		Correa reflexa	a	a	a	a
		Zieria arborescens				+
Santalaceae		Exocarpos cupressiformis	+	+	o	a
Stackhousiaceae		Stackhousia monogyna			+	
Stylidiaceae		Stylidium graminifolium	+			
Tremandraceae	e,s	Tetratheca gunnii	+	+	+	o
		Tetratheca pilosa	+			o
Thymelaeaceae		Pimelea humilis	o	+		
		Pimelea nivea			+	o
Violaceae		Viola hederacea	+	o	+	+
MONOCOTYLEDONS						
Cyperaceae		Gahnia grandis	+	+	o	a
		Gahnia radula		o	+	+
		Lepidosperma elatius		o		
		Lepidosperma laterale	+	+	o	+
	e	Lepidosperma lineare var.inops	o		+	+
		Schoenus apogon			+	+
Liliaceae		Arthropodium milleflorum		+		
		Dianella revoluta			+	
Orchidaceae		Acianthus exsertus			+	
		Chiloglottis sp.	+		+	+
		Glossodia major			+	
		Pterostylis longifolia			+	
		Pterostylis nutans	+	+	+	+
		Thelymitra sp.		+		
Poaceae		*Deyeuxia quadriseta*	+	+		
		Microlaena stipoides	+	o	+	
		Poa sieberana Spreng.	o	o	+	+
	e	*Stipa aphylla*	o	o	o	+
		Tetrarrhena distichophylla	+	+	+	
		Themeda australis	+	o		
Xanthorrhoeaceae		*Lomandra longifolia*	o	o	o	o

BIRDS IN A PARTLY CLEARFELLED DRY EUCALYPT FOREST ON DOLERITE IN SOUTHEASTERN TASMANIA

by K.J.M. Dickinson, L.E. Wall and R.I. Wilson

(with two tables and three text-figures)

DICKINSON, K.J.M., WALL, L.E. & WILSON, R.I., 1986 (12:ix): Birds in a partly clearfelled dry eucalypt forest on dolerite in southeastern Tasmania. *Pap. Proc. R. Soc. Tasm.* 120: 39–49. ISSN 0080-4703. Department of Geography, University of Tasmania, now Botany Department, University of Otago, Box 56, Dunedin, New Zealand; 63 Elphinstone Road, Mt Stuart, Tasmania; and 53 Blowhole Road, Blackmans Bay, Tasmania.

An area of dry eucalypt forest on dolerite in southeastern Tasmania was clearfelled in 1981. A portion of this area was subsequently slash-burnt and aerially sown in 1982, whilst the rest of the area was left unburnt and unsown. A monthly bird census was conducted during 1983-1984 in surrounding uncut, mature forest and also on the clearfelled area. Species were recorded together with the habitat in which they occurred and the particular plant species being utilised. A total of 46 avian species were recorded during the monthly censuses, with most species and individuals being observed in the spring months. The numbers of species and individuals recorded on the burnt and unburnt clearfelled areas were low in comparison with those observed in the uncut forest. In general, those species able to utilise open-ground habitats tended to be the least affected by clearfelling followed by slash-burning. However, the unburnt clearfelled area provided foraging sites for certain species, in preference to the nearby slash-burnt area. Many individuals recorded in the clearfelled areas made use of trees left standing after logging. The use of fire in dry forest management practice and the importance of cull trees are discussed.

Key Words: Tasmania, birds, clearfelled eucalypt forest, fire, forest management

INTRODUCTION

The large-scale exploitation of the dry eucalypt forests on dolerite in southeastern Tasmania began in 1971, with the provision of a woodchip market in Japan and a processing mill at Triabunna (fig. 1). Current forest management practice involves the logging of all merchantable trees (known as clearfelling) over large areas (termed coupes) typically 200 to 400 ha in size. In most cases clearfelling is followed by broadcast burning of slash (residue left after logging operations) and the sowing of eucalypt seed from the air.

The lack of data regarding the effects of clearfelling on wildlife has been emphasized by Conner & Adkisson (1975) for North America, and by Statham (1984) for Australia. Fauna vary in their ability to withstand the disturbance, the most severely affected being those vertebrates and invertebrates which are dependent on mature trees for feeding and breeding (Franzreb 1977, McIlroy 1978, Recher *et al.* 1981).

In Australia, information pertaining to the impact of forest utilisation on the avifauna is more extensive than for other vertebrate or invertebrate groups (e.g. Cowley 1971, Pattemore & Kikkawa 1975, Woinarski 1979, Loyn 1980, Pattemore 1980, Smith 1985), probably because birds are easier to study on a regular basis (Statham 1984).

Clearfelling dramatically truncates the vertical vegetation structure of the natural forest. Consequently, wildlife which can exploit open ground for both feeding and breeding tends to be the least affected in the first few years following cutting (Conner & Adkisson 1975, Loyn *et al.* 1980, Pattemore 1980). As the forest regenerates, birds have been observed to follow a succession in which different species become abundant as the structural diversity of the vegetation increases (Green 1980, Franzreb 1977, Loyn *et al.* 1980, Pattemore 1980).

The effect on fauna of forest management which involves the use of fire has received some attention. The influence of prescribed burning (generally involving fires of low to medium intensity) under mature or regenerating stands has been considered by Cowley *et al.* (1969), Leonard (1970), Cowley (1971), Christensen & Kimber (1975), and McIlroy (1978). Fuel reduction burning affects bird species which feed and nest on the ground (Cowley 1971) but little is known of the impact on wildlife of fires which occur at particular times of the year (McIlroy 1978). Study of the effects of the hot, intense fires associated with slash-burning has been largely neglected (Pattemore 1980).

This paper seeks to provide some data on the effects of clearfelling, with and without slash-burning, on wildlife within dry forests. Due to a limited amount of time being available a survey of the bird population was chosen as a means of giving some indication of the sensitivity of wildlife to habitat change.

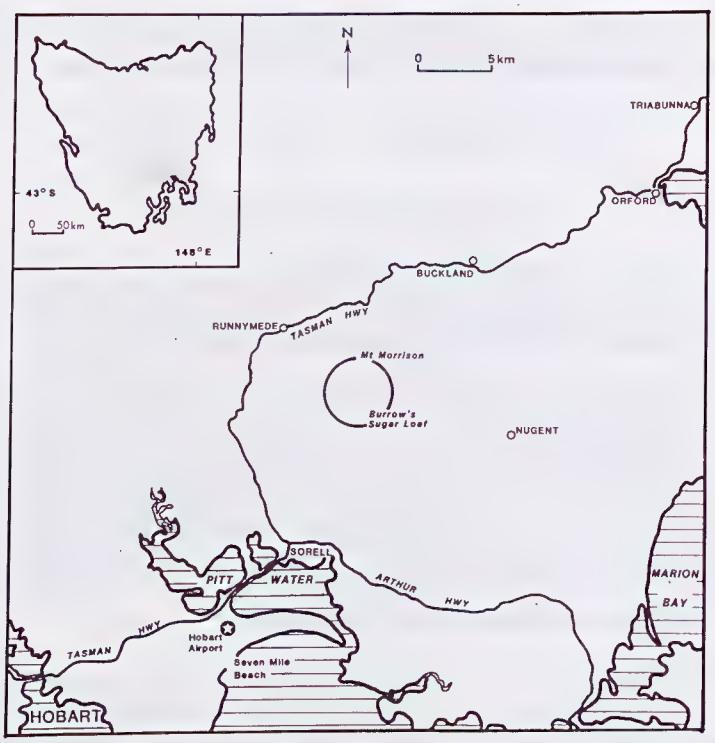

FIG.1 — The location in southeastern Tasmania of the study area at MM14 (circled).

METHODS

A bird census was conducted in the environs of the coupe Mt Morrison block, compartment 14, hereafter referred to as MM14 (fig. 1), which contained vegetation types typical of those found in dry eucalypt forests on dolerite in southeastern Tasmania. The study area chosen was within 6 km of the nearest pasture and formed part of an intensive investigation of vegetation and fuel dynamics following dry forest utilisation (Dickinson 1985).

The forest present within the coupe was treated in two ways:

(a) clearfelling followed by slash-burning and aerial sowing of eucalypt seed (hereafter referred to as treatment B), and

(b) clearfelling without slash-burning or aerial sowing (hereafter referred to as treatment UB).

Clearfelling took place in winter 1981, the slash-burn on 11 January 1982 and the aerial sowing of seed in April 1982.

The census was carried out during 1983 and 1984 at approximately monthly intervals, with all surveys being undertaken during the morning between the hours of 0830 and 1200. Individual surveys lasted approximately two hours. On each occasion the general weather conditions were noted (appendix 1). Bird species were recorded along a 3 km transect through uncut mature forest near to the coupe, with the route being chosen so as to cover the diversity of habitats present in the region of MM14 (fig. 2). The general habitats included:

1. Creekside vegetation which consisted of thick undergrowth close to a water course or soak. The plant species were represented by various graminoids, shrubs and small trees, such as *Acacia melanoxylon, A. verticillata, Gahnia grandis, Lepidosperma laterale* and *Leptospermum lanigerum*.
2. Forest dominated by *Eucalyptus obliqua* but with various other eucalypt species present, including *E. globulus* and *E. viminalis*. The understorey consisted of a combination of graminoids, ferns, small trees and shrubs, for example *Acacia dealbata, Epacris impressa, Gahnia grandis, Leptospermum scoparium* and *Pteridium esculentum*.

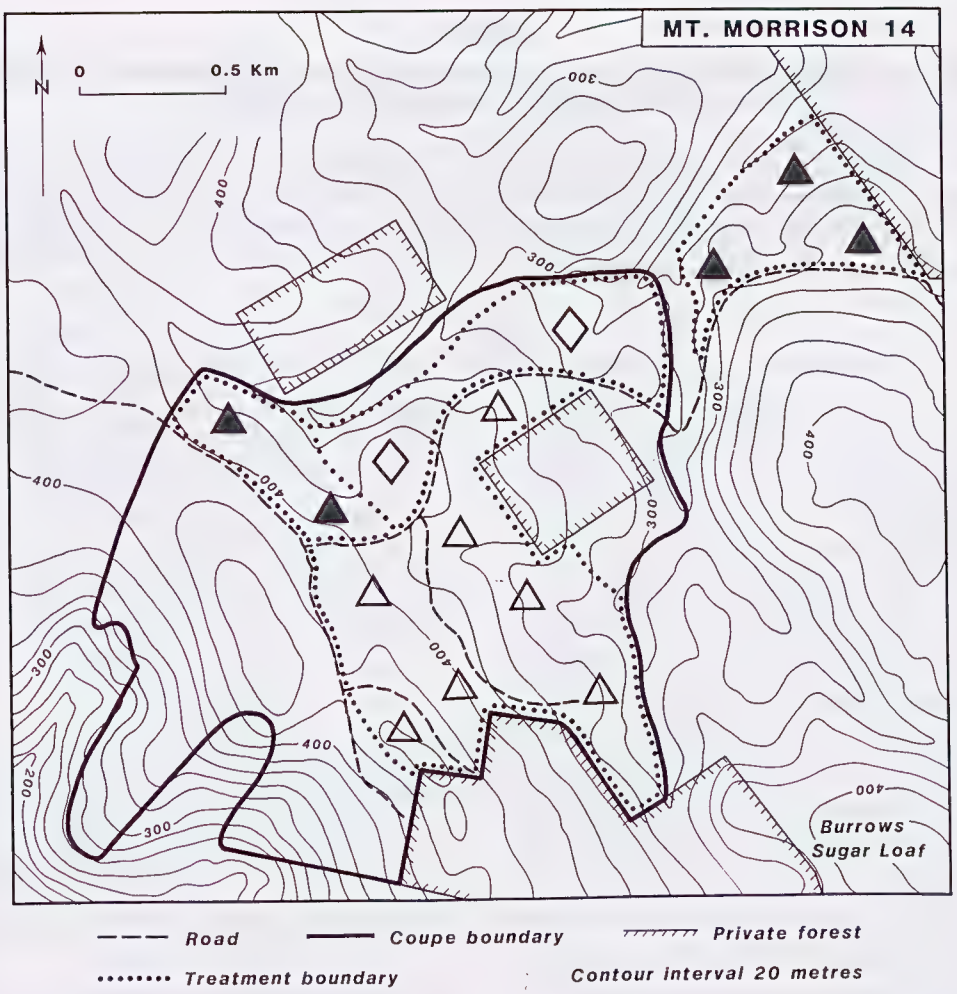

FIG.2 — The route of the monthly bird census at MM14 through uncut forest (▲); on the area which had been clearfelled and slash-burnt, B (△); and on the area which was clearfelled but with the slash left unburnt, UB (◊).

3. Forest dominated by *Eucalyptus pulchella* interspersed with individuals of *E. amygdalina, E. globulus* and *E. viminalis*. The understorey consisted generally of a sparse cover of herbs, graminoids, small shrubs and tussock grasses, for example *Acacia dealbata, A. stricta, Diplarrhena moraea, Helichrysum scorpioides, Lissanthe strigosa* and *Poa* spp.
4. The margins of uncut forest, dominated by *Eucalyptus obliqua*, and the part of the coupe MM14 which had been slash-burnt (treatment B).

In addition, from March 1984 the census was extended to include sweeps of the central areas of treatment B and treatment UB (fig. 2). On each occasion sweep duration was approximately 45 minutes and 30 minutes respectively.

In all censuses bird species were recorded either as actual sightings or as vocal records only, when the bird was not seen. In the case of sightings, the general habitat in which the bird species occurred was noted, as well as the activity in which the particular individual(s) was (were) engaged. Sightings were registered as single observations even when more than one individual of the species was present. Notes were also made of the plant

TABLE 1

The Total Number of Sightings and Total Number of Bird Species Recorded at MM14 During the Monthly Censuses in 1983 and 1984.

Part A = the total number of records and sightings, together with the frequency of sightings recorded in the various habitats in uncut forest. Air = species recorded in flight at a height >41 m; Cr = species recorded in creekside vegetation; M = species recorded crossing the margins of uncut forest and clearfelled coupe; O = species recorded in *Eucalyptus obliqua* dominated forest; P = species recorded in *E. pulchella* dominated forest. ( ) = species was very abundant in certain censuses with almost constant calling. Part B = the total number of records and sightings recorded during the sweeps on treatments B and UB.

	PART A							PART B			
	Total number of sightings	Total number of records	Frequency of sightings General habitat					Total number of sightings		Total number of sightings	
Species			Air	Cr	M	O	P	B	UB	B	UB
Wedge-tailed Eagle	1	1	1	—	—	—	—	—	—	—	—
Brown Falcon	4	4	4	—	—	—	—	1	—	1	—
Common Bronzewing	1	2	—	—	—	1	—	—	—	—	—
Brush Bronzewing	1	1	1—	—	—	1	—	—	—	—	—
Green Rosella	37	64	1	1	2	21	12	3	1	3	1
Blue-winged Parrot	—	—	—	—	—	—	—	2	—	2	—
Pallid Cuckoo	1	2	—	—	—	—	1	—	—	—	—
Fan-tailed Cuckoo	5	19	—	—	—	5	—	—	—	—	—
Laughing Kookaburra	4	19	—	—	—	4	—	—	1	2	2
Skylark	—	—	—	—	—	—	—	1	—	1	—
Welcome Swallow	2	2	—	—	2	—	—	2	—	2	—
Black-faced Cuckoo-shrike	1	1	—	—	—	1	—	—	—	—	—
White's Thrush	2	2	—	—	—	2	—	—	—	—	—
Flame Robin	9	11	—	—	—	5	4	20	1	20	1
Scarlet Robin	14	17	—	1	2	7	4	1	1	1	1
Dusky Robin	17	20	—	1	6	10	—	10	—	13	—
Golden Whistler	13	26	—	—	1	6	6	—	1	1	1
Grey Shrike-thrush	30	68	—	1	4	21	4	5	—	7	1
Satin Flycatcher	10	(21)	—	1	—	8	1	—	—	—	—
Grey Fantail	54	58	—	17	2	30	5	—	—	—	—
Spotted Quail-thrush	4	4	—	—	—	1	3	—	—	—	—
Superb Fairy-wren	71	76	—	20	19	20	12	31	6	31	8
White-browed Scrub-wren	17	21	—	13	1	3	—	1	—	1	—
Calamanthus	—	—	—	—	—	—	—	1	—	1	—
Brown Thornbill	82	91	—	13	10	41	18	4	7	4	7
Tasmanian Thornbill	34	38	—	16	-	14	4	1	—	1	—
Yellow-rumped Thornbill	—	1	—	—	—	—	—	1	—	1	—
Yellow Wattlebird	2	8	—	—	1	—	1	—	—	—	—
Yellow-throated Honeyeater	19	31	—	—	—	13	6	—	1	—	2
Strong-billed Honeyeater	18	20	—	—	—	18	—	—	—	—	—
Black-headed Honeyeater	36	39	—	—	1	29	6	—	—	—	1
Crescent Honeyeater	51	77	2	1	—	37	11	—	8	—	11
New Holland Honeyeater	1	1	—	—	—	—	1	—	—	—	—
Eastern Spinebill	38	62	—	6	1	25	6	1	12	1	14
Spotted Pardalote	11	20	—	—	1	9	1	1	1	1	1

Species	PART A Total number of sightings	Total number of records	Frequency of sightings General habitat Air	Cr	M	O	P	PART B Total number of sightings B	UB	Total number of sightings B	UB
Striated Pardalote	27	(52)	—	—	—	20	7	4	—	4	3
Silvereye	5	9	—	1	—	4	—	1	—	1	—
Beautiful Firetail	6	6	—	—	5	1	—	2	—	2	—
Dusky Woodswallow	—	1	—	—	—	—	—	1	—	1	—
Grey Butcherbird	1	7	—	—	—	—	1	—	—	—	—
Black Currawong	12	23	5	1	1	5	—	—	1	2	2
Grey Currawong	7	16	1	1	—	4	1	—	2	—	2
Forest Raven	10	21	8	—	—	1	1	1	1	2	1

Additional species (recorded by call only): Yellow-tailed Black-Cockatoo, Shining Bronze-Cuckoo, European Goldfinch.

species associated with each sighting, together with the height class in which the bird species occurred. The latter were based on the structural divisions used in the TASFORHAB classification system (Peters 1985, see table 2). In addition, general observations of bird species occurring at MM14 were made during the years 1981 to 1984. Nomenclature of bird species follows Schodde *et al.* (1977).

RESULTS

The English and scientific names of the bird species recorded at MM14 during 1981 to 1984 are given in appendix 2. The 46 species recorded during the monthly censuses, as well as the total number of sightings and general habitat in which they were recorded, are presented in table 1.

The Censuses Covering the Various Habitats in Uncut Forest

The number of bird species, sightings and vocal records varied with season (fig. 3) and with weather conditions at the time of, and for the few days preceding the census (appendix 1). Feeding activity tended to be more pronounced if the census coincided with a period following inclement weather. Activity increased during the breeding season covered by the spring months of September and October, with the maximum number of species (27) being recorded in October 1983. The greatest number of sightings (77) was also made on the latter occasion. In comparison, the numbers of species, sightings and vocal records were low during the winter months of June to August (fig. 3).

Several species were absent or infrequent at certain times of the year, for example the Striated Pardalote was extremely abundant from September to November in both 1983 and 1984, whilst the Satin Flycatcher was abundant only from November 1983 to February 1984, reappearing in the last census in November 1984. In contrast, the Crescent Honeyeater was most frequent during late autumn and winter.

The most frequently recorded species during the monthly censuses were the Brown Thornbill, Crescent Honeyeater, Superb Fairy-wren and Grey Shrike-thrush. Ten species, which included the Wedge-tailed Eagle, Spotted Quail-thrush and White's Thrush, were recorded on four or less occasions. However, Wedge-tailed Eagles were observed at other times, particularly on clear calm days, hunting in pairs over the coupe and surrounding forest. In February 1984, one pair was disturbed feeding on a freshly killed Bennett's wallaby (*Macropus rufogriseus*) within nearby mature forest dominated by *Eucalyptus pulchella*.

In general, the favoured habitats were those containing creekside vegetation and forest dominated by *E. obliqua*, although the situation was complicated by the varying lengths of transect through the different vegetation types. During the course of the censuses, 23 and 31 bird species were recorded in forest dominated by *E. pulchella*, and by *E. obliqua* respectively. The numbers of sightings and vocal records tended to be greater in *E. obliqua* dominated communities with certain species commonly occurring together, for example Black-headed Honeyeaters and Strong-billed Honeyeaters often foraged in flocks through the foliage of *E. obliqua*. In the months of May to August it was not uncommon to have large sections of the transect where no sightings or vocal records were made. These gaps in observations would then be interspersed with pulses of bird species activity concentrated in particular areas of mature forest, generally those dominated by *E. obliqua*. This phenomenon was not so evident in the *E. pulchella* dominated habitats which were located on the more exposed, rocky ridges. In addition, on days

TABLE 2

The Bird Species Recorded at MM14 During the Monthly Censuses in 1983 and 1984, Together with the Frequency of Their Occurrence in Eight Height Classes (m).

A = recorded in the various habitats in uncut forest (see text); B = recorded during the sweeps on treatment B; UB = recorded during the sweeps on treatment UB. Some individuals were recorded in more than one class.

	Height Class (m)																							
	0-2			2-5			5-8			8-15			15-27			27-41			>41			Flying>41		
	A	B	UB	A	B	UB	A	B	UB	A	B	UB	A	B	UB	A	B	UB	A	B	UB	A	B	UB
Wedge-tailed Eagle	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—
Brown Falcon	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	4	1	—
Common Bronzewing	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Brush Bronzewing	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Green Rosella	5	2	1	2	—	—	4	—	1	10	1	—	14	—	—	8	—	—	—	—	—	2	—	—
Blue-winged Parrot	—	1	—	—	—	—	—	1	—	—	—	—	—	1	—	—	2	—	—	—	—	—	—	—	—
Pallid Cuckoo	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—
Fan-tailed Cuckoo	1	—	—	—	—	—	—	—	—	2	—	—	—	—	—	2	—	—	—	—	—	—	—	—	—
Laughing Kookaburra	—	—	—	—	—	—	—	—	—	1	—	—	3	—	—	—	—	1	—	—	—	—	—	—	—
Skylark	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Welcome Swallow	—	—	—	—	—	—	—	—	—	2	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Black-faced Cuckoo-Shrike	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—
White's Thrush	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Flame Robin	2	14	1	2	2	—	1	1	—	5	1	—	1	2	—	—	—	—	—	—	—	—	—	—	—
Scarlet Robin	5	1	—	2	—	—	2	—	1	2	—	—	3	—	—	1	—	—	—	—	—	—	—	—	—
Dusky Robin	4	5	—	4	3	—	3	—	—	3	2	—	4	—	—	—	—	—	—	—	—	—	—	—	—
Golden Whistler	2	—	—	2	—	—	—	—	—	1	—	1	6	—	—	3	—	—	1	—	—	—	—	—	—
Grey Shrike-thrush	—	—	—	1	1	—	2	1	—	9	1	1	14	2	—	2	—	—	2	—	—	—	—	—	—
Satin Flycatcher	—	—	—	2	—	—	—	—	—	2	—	—	5	—	—	2	—	—	—	—	—	—	—	—	—
Grey Fantail	13	—	—	23	—	—	3	—	—	7	—	—	6	—	—	2	—	—	—	—	—	—	—	—	—
Spotted Quail-thrush	4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Superb Fairy-wren	52	29	6	14	2	1	3	—	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
White-browed Scrub-wren	17	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Brown Thornbill	24	2	1	20	—	1	3	—	1	15	2	3	16	—	2	8	—	—	—	—	—	—	—	—	—
Tasmanian Thornbill	13	1	—	10	—	—	4	—	—	6	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—
Yellow-rumped Thornbill	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Yellow Wattlebird	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—
Yellow-throated Honeyeater	—	—	—	1	—	—	2	—	1	4	—	—	8	—	—	4	—	—	1	—	—	—	—	—	—
Strong-billed Honeyeater	—	—	—	—	—	—	1	—	—	5	—	—	10	—	—	4	—	—	1	—	—	—	—	—	—
Black-headed Honeyeater	—	—	—	1	—	—	—	—	—	6	—	—	14	—	—	15	—	—	1	—	—	—	—	—	—
Crescent Honeyeater	2	—	—	4	—	1	4	—	1	12	—	3	16	—	3	12	—	—	2	—	—	—	—	—	—
New Holland Honeyeater	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—
Eastern Spinebill	11	1	3	12	—	4	4	—	4	8	—	3	3	—	—	—	—	—	—	—	—	—	—	—	—
Spotted Pardalote	—	—	—	—	—	—	—	—	—	2	—	1	5	1	—	3	—	—	1	—	—	—	—	—	—
Striated Pardalote	—	1	—	1	—	—	—	—	—	5	2	—	6	1	—	15	—	—	—	—	—	—	—	—	—
Silvereye	2	—	—	1	—	—	1	—	—	—	—	—	—	1	—	1	—	—	—	—	—	—	—	—	—
Beautiful Firetail	—	1	—	3	1	—	—	—	—	3	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—
Dusky Woodswallow	—	—	—	—	—	—	—	1	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Grey Butcherbird	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Black Currawong	—	—	—	1	—	—	1	—	1	2	—	—	2	—	—	1	—	1	—	—	—	6	—	—
Grey Currawong	—	—	—	1	—	—	—	—	1	2	—	1	1	—	—	2	—	—	1	—	—	—	—	—
Forest Raven	—	—	—	—	—	+	—	—	—	—	—	1	—	—	—	1	—	—	—	—	—	9	—	—

Additional species (recorded by call only): Yellow-tailed Black-Cockatoo, Shining Bronze-Cuckoo, European Goldfinch.

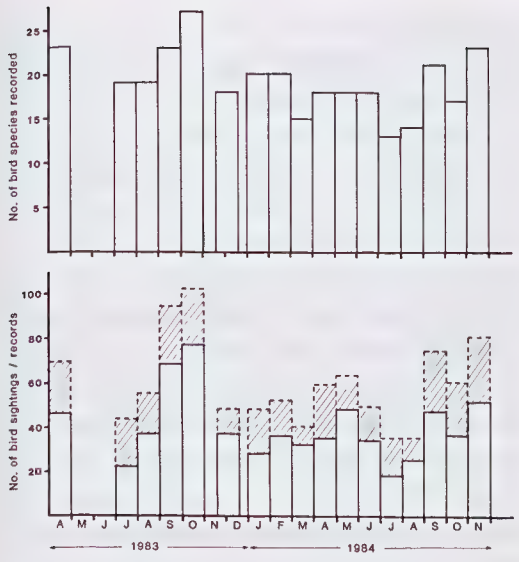

FIG.3 — The numbers of bird species recorded at MM14 during each of the monthly censuses in 1983 and 1984, together with the number of sightings and the number of vocal records (shaded) noted on each occasion. ND = no data.

when there were strong winds bird activity tended to be concentrated in the more sheltered habitats, generally along creeks or on the lower slopes between ridges, rather than on the more exposed rocky sections.

The Tasmanian Thornbill, Brown Thornbill, Superb Fairy-wren, Grey Fantail and White-browed Scrub-wren were the most commonly observed species in creekside vegetation. The Brown Thornbill and Superb Fairy-wren also frequented the areas where uncut forest abutted clearfelled coupe, as well as the Beautiful Firetail which was sighted crossing the forest margins on five out of a total of six occasions. However, it is likely that these species were more difficult to observe in the uncut forest.

The height classes in which bird species were recorded are given in table 2. The Spotted Quail-thrush, White-browed Scrub-wren and White's Thrush were restricted to the lowest class of 0 to 2 m. The Tasmanian Thornbill, Beautiful Firetail, Superb Fairy-wren and Flame Robin were most commonly sighted in classes up to 15 m. The Grey Shrike-thrush, Black Currawong and Grey Currawong were more commonly observed above 8 m. The Tasmanian endemics, the Yellow-throated Honeyeater, Black-headed Honeyeater and Strong-billed Honeyeater favoured the height classes from 8 to 41 m. The Brown Thornbill, Crescent Honeyeater, Green Rosella and Grey Fantail were recorded feeding in the full range of height classes from 0 to 41 m.

During the censuses several nests were observed belonging to the Forest Raven and Black Currawong, as well as two belonging to the Tasmanian endemic Yellow Wattlebird. Individuals of the Green Rosella were seen inspecting a hole in the trunk of an *Eucalyptus viminalis* tree in April 1983 after the end of the main breeding season, and juveniles were observed in January and February 1984. Spotted Pardalote juveniles were observed in November 1983 feeding in the foliage of *E. obliqua*, whilst evidence of nesting by the Striated Pardalote was recorded in September and October 1983, and November 1984. Juveniles of the Pallid Cuckoo (January 1984), Fan-tailed Cuckoo (February 1984), Superb Fairy-wren, Strong-billed Honeyeater (February 1984), Black-headed Honeyeater (February 1984), Satin Flycatcher (February 1984) and Grey Fantail (February 1984) were also observed. A Brown Thornbill was observed carrying nesting material in August 1984.

The Censuses Covering the Sweeps on Treatments B and UB

The most commonly observed species on treatment B were the Superb Fairy-wren, Flame Robin and Dusky Robin (table 1). All were commonly seen feeding from 0 to 2 m or perched on dead trees or stumps (table 2). The Skylark, Blue-winged Parrot and Calamanthus were recorded only on treatment B (table 1). Small flocks of the Blue-winged Parrot, numbering up to 14 individuals, were observed consistently on treatment B either feeding on the ground or perched on dead trees from November to March in the years 1982/1983 and 1983/1984.

On treatment UB the most commonly observed species was the Eastern Spinebill which frequented the structural classes from 0 to 15 m, feeding preferentially in the understorey vegetation from 0 to 5 m. The Superb Fairy-wren did not favour treatment UB to the same extent as treatment B, even allowing for the differences in length of the indiviual sweeps. The majority of the other species recorded on both treatments were seen perched or feeding in the foliage of the few standing trees (culls) which had retained their canopy following forest utilisation.

DISCUSSION

The seasonal and day-to-day variation in bird behaviour observed in this study has been

noted elsewhere (e.g. Driscoll 1977, Ratkowsky & Ratkowsky 1977, Pattemore 1980, Thomas 1980). Various species which were absent for much of the year from MM14 are summer migrants which come to Tasmania from the Australian mainland, for example the Satin Flycatcher, Welcome Swallow and Blue-winged Parrot (Pattemore 1980). Most of the honeyeater species are nomadic with a tendency to move to low altitudes in winter (Thomas 1980). During the censuses at MM14 the Eastern Spinebill was particularly abundant when the heath species *Epacris impressa* was in flower, which generally occurred in late autumn and winter. In addition, the Crescent Honeyeater was noticeably more numerous in late autumn and winter. The increased activity of the Striated Pardalote at certain times of the year has also been observed within dry forests by Pattemore (1980), who noted a greater abundance of the species during the breeding season from November to February than in other months.

The influence of weather conditions on bird numbers which was observed during the present study has also been described by Ratkowsky & Ratkowsky (1979) during surveys on Mt Wellington, near Hobart. Heavy rain or windy conditions may depress bird activity by reducing the availability of insects for forage (Franzreb 1977).

Dry sclerophyll forest in Tasmania supports 59 species out of a total of 70 regular forest birds (Thomas 1979). The total number of species in any one locality depends on the structural complexity, foliage density, and maturity of the forest (MacArthur & MacArthur 1961, MacArthur 1964, Recher 1971, Loyn *et al.* 1980, Friend 1982). Moreover, bird populations tend to be greater in gullies than on ridges (see Loyn 1980, Smith 1984,1985). Where one habitat abuts on another, as in the case of the margins of uncut forest and the clearfelled coupe, a number of species can make use of both environments (c.f. Friend 1982).

Similar foraging habitats to those used by the avifauna observed at MM14 have been described by Pattemore (1980) and Wilson (1981) both of whom wrote on the effect of forest utilisation on dry forest birds. Both authors describe mature forest as supporting the highest number of avian species whereas in contrast, areas which had been clearfelled supported low bird species numbers for the first few years following utilisation. The results from the sweeps on treatments B and UB at MM14 indicate that bird species which can exploit open ground habitats, such as the Superb Fairywren and Blue-winged Parrot, are able to utilise a slash-burnt environment for at least two years after burning. However, unburnt slash can provide important foraging sites in their own right, as made evident by Conner & Adkisson (1975) for some North American species, and by Loyn *et al.* (1980) for certain birds in Victoria.

Nevertheless, not all species which utilise the lowest vegetation stratum of 0 to 2 m are unaffected by clearfelling. For example, White's Thrush, a species common in wet forest habitats (Blakers *et al.* 1984) but not usually associated with dry communities, was only recorded in undergrowth within the forest dominated by *E. obliqua*. In addition, some concern has been expressed over the status of the Spotted Quail-thrush in areas of clearfelled forest. The Spotted Quail-thrush was not recorded outside uncut forest at MM14, however Pattemore (1980) observed the species in regrowth forest on a sandstone site which had not been slash-burnt. Wilson (1981) suggested that the species may better withstand logging activity if the forest is allowed to regenerate without the use of fire.

The importance of cull trees within clearfelled areas as foraging sites and perches for certain bird species has also been documented by Loyn *et al.* (1980), who noted that the Dusky Woodswallow and Flame Robin required cull trees for both perches and nest sites. Dead standing trees within forest habitats have a multipurpose role in the life cycle of many fauna (McClelland & Frissell 1975) making it important to identify, and retain, cull trees in any forest management practice. The nesting requirements of many Australian landbirds have been emphasised by Disney & Stokes (1976), who stated that in dry sclerophyll forest holes of suitable size for nesting may take in excess of 100 years to develop. Thus, from a wildlife viewpoint the retention of cull trees of varying ages following clearfelling is likely to provide a supply of suitable breeding sites within the regenerating forest, until such time that the regrowth eucalypts form their own holes (c.f. Smith 1985). It can be seen that within a forest industry managed on rotation cycles of less than 80 years, there is little chance that trees will have developed holes of suitable size and number to support the full range of dry forest fauna. Bowman & Jackson (1981) quote possible rotation cycles in Tasmanian dry eucalypt forests of 40 to 50 years from Forestry Commission documentation, with the additional proviso that these time periods are open to amendment. The harvest rotation cycles currently proposed are of 80 to 90 years duration (Tasmanian Woodchip Export Study Group 1985). Of the avian species, examples of those most likely to be affected by a lack of suitable size holes are the Yellow-tailed Black-

cockatoo and Swift Parrot, the Tasmanian endemic Green Rosella, and the owl species, the Southern Boobook and the Masked Owl, all of which feed and nest in mature trees (Pattemore 1980, Wilson 1981). Further research is needed into the optimal density and spacing of cull trees in order to maximise the forage, nest and perch sites available to wildlife in clearfelled areas.

Prescribed burning undertaken beneath the regenerating forest during the course of a particular forestry rotation cycle may be disadvantageous to some species, especially those which depend on ground habitats (e.g. Spotted Quail-thrush). The management strategy involving fires of varying intensity, patchy distribution and differing fire-free interval has been advocated by Cowley (1971), Christensen & Kimber (1975), Loyn (1980), and Fox & McKay (1981). In addition, a mosaic of mature forest covering habitats spanning ridges and gullies and linking different drainage areas, as well as regenerating stands of varying ages, is seen as a minimum requirement for wildlife management within any dry forest used by industry (Loyn *et al.* 1980, Pattemore 1980, Recher *et al.* 1981, Statham 1984).

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APPENDIX 1

The Dates of the Bird Censuses Undertaken at MM14 During 1983 and 1984, Together with Descriptions of the Prevailing Weather Conditions.

Date of Census	Weather Conditions
12.4.83	Clear skies. Very light breeze. Warm.
5.7.83	Clear skies. Calm. Cool-warm. (Previous 10 days severe frosts and snow.)
3.8.83	Clear skies. Very light breeze. Cold.
10.9.83	Intermittent light cloud. Light N breeze. Cool-warm. (Previous 5 days almost constant rain.)
5.10.83	95% cloud cover. Light S breeze. Cool.
30.11.83	100% cloud cover. Strong N breeze. Cool-warm.
3.1.84	30% to 100% cloud cover. Strong SW breeze. Cool.
7.2.84	10% cloud cover. Moderate N breeze. Cool-warm.
1.3.84	95% cloud cover. Very light breeze. Cold-cool following heavy rain.
3.4.84	5% cloud cover. Light W breeze. Warm.
2.5.84	Clear skies. Calm. Cold-cool.
19.6.84	100% cloud cover. Calm. Cold.
12.7.84	30% to 100% cloud cover. Calm. Cold-cool.
9.8.84	100% cloud cover. Moderate N breeze. Cool.
13.9.84	100% cloud cover (light high altitude cloud). Light NE breeze. Cool-warm.
8.10.84	100% cloud cover. Strong N breeze. Cool-warm.
14.11.84	15% cloud cover. Moderate SE breeze. Cool-warm following heavy rain.

APPENDIX 2

Bird Species Observed at MM14 During the Years 1981-1984

Nomenclature follows Schodde *et al.* 1977). * = species endemic to Tasmania.

	Wedge-tailed Eagle	*Aquila audax*
	Brown Falcon	*Falco berigora*
	Common Bronzewing	*Phaps chalcoptera*
	Brush Bronzewing	*Phaps elegans*
	Yellow-tailed Black-Cockatoo	*Calyptorhynchus funereus*
	Swift Parrot	*Lathamus discolor*
*	Green Rosella	*Platycercus caledonicus*
	Blue-winged Parrot	*Neophema chrysostoma*
	Pallid Cuckoo	*Cuculus pallidus*
	Fan-tailed Cuckoo	*Cuculus pyrrhophanus*
	Shining Bronze-Cuckoo	*Chrysococcyx lucidus*
	White-throated Needletail	*Hirundapus caudacutus*
	Laughing Kookaburra	*Dacelo novaeguineae*
	Skylark	*Alauda arvensis*
	Welcome Swallow	*Hirundo neoxena*
	Tree Martin	*Cecropis nigricans*
	Black-faced Cuckoo-shrike	*Coracina novaehollandiae*
	White's Thrush	*Zoothera dauma*
	Flame Robin	*Petroica phoenicea*
	Scarlet Robin	*Petroica multicolor*
*	Dusky Robin	*Melanodryas vittata*
	Olive Whistler	*Pachycephala olivacea*
	Golden Whistler	*Pachycephala pectoralis*
	Grey Shrike-thrush	*Colluricincla harmonica*
	Satin Flycatcher	*Myiagra cyanoleuca*
	Grey Fantail	*Rhipidura fuliginosa*
	Spotted Quail-thrush	*Cinclosoma punctatum*
	Superb Fairy-wren	*Malurus cyaneus*
	White-browed Scrub-wren	*Sericornis frontalis*
	Calamanthus	*Sericornis fuliginosus*
	Brown Thornbill	*Acanthiza pusilla*
*	Tasmanian Thornbill	*Acanthiza ewingii*
	Yellow-rumped Thornbill	*Acanthiza chrysorrhoa*
*	Yellow Wattlebird	*Anthochaera paradoxa*
*	Yellow-throated Honeyeater	*Lichenostomus flavicollis*
*	Strong-billed Honeyeater	*Melithreptus validirostris*
*	Black-headed Honeyeater	*Melithreptus affinis*
	Crescent Honeyeater	*Phylidonyris pyrrhoptera*
	New Holland Honeyeater	*Phylidonyris novaehollandiae*
	Eastern Spinebill	*Acanthorhynchus tenuirostris*
	Spotted Pardalote	*Pardalotus punctatus*
	Striated Pardalote	*Pardalotus striatus*
	Silvereye	*Zosterops lateralis*
	European Goldfinch	*Carduelis carduelis*
	Beautiful Firetail	*Emblema bella*
	Dusky Woodswallow	*Artamus cyanopterus*
	Grey Butcherbird	*Cracticus torquatus*
*	Black Currawong	*Strepera fuliginosa*
	Grey Currawong	*Strepera versicolor*
	Forest Raven	*Corvus tasmanicus*

OBSERVATIONS ON SOME TASMANIAN FISHES: PART XXXI — REVIEW OF GNATHANACANTHIDAE

by the late E.O.G. Scott

(with four tables, four text-figures and three plates)

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GNATHANACANTHIDAE. The sole representative of this family, *Gnathanacanthus goetzeei* Bleeker, 1855, specified in the last century as the type of three different genera by Dutch, English and Australian ichthyologists, with type locality Tasmania (twice), Victoria, and endemic to southern Australian waters, is here made the subject of detailed investigation based on 15 individuals. Fin spines and rays are specified by rectified exponential equations. Differential growth with age is recognized; consistent negative correlation of the lengths of fin spines and rays with overall length of fish occurs. Features not previously reported include: presence of a subrectangular fleshy intermandibular pad, not matched in other families of the suborder Scorpaenoidei; disposition of dermal papillae, known to be irregular on the head and body, in parallel rows on the fins; and intrusion beneath the upper margin of operculum of a slip of papillate integument.

Key Words: Tasmania, fish, Gnathanacanthidae.

INTRODUCTION

This paper follows the general plan of others in the series. Linear dimensions are given throughout in millimetres or as thousandths of standard length. The symbols *Ls, Lt, TLs* and *TLt* denote standard length, total length, thousandths of standard length and thousandths of total length, respectively. Registration numbers are those of the Queen Victoria Museum and Art Gallery, Launceston. Certain other conventions are noted in earlier contributions.

FAMILY GNATHANACANTHIDAE

In current Australian literature the remarkable fish *Gnathanacanthus goetzeei* Bleeker, 1885, of which the River Derwent is the type locality, is accepted as the only species of its genus, which in turn is the sole representative of its family, the Gnathanacanthidae, proposed in 1891 by Gill for its accommodation. Its status at specific, at generic and at familial levels has involved considerable debate and no little confusion, particularly in respect of the higher taxa; the question of species being, with a single exception, restricted to that of type-species and hence to that extent coextensive with that of genus.

In 1855 with the unique holotype of a new species before him Bleeker defined *Gnathanacanthus* as follows: "Caput corpusque compressa. Spinae capite nullae. Cristae occipitales sejuntae ossa interspinosa amplectentes. Dentes maxillis parvi pluriserali; vomerini palatinique nulli. Pinnae dorsalis et analis a caudali sejuntae, dorsalis vertice insipiens, in parte spinosa profunde incisa. Radii pinnis omnibus simplices, liberi nulli, ventrali 1/5. Spinae anales 3. Membrana branchiostega radiis 7." He noted that the new genus is related to the genera *Agriopus* Cuvier, Blepsias Cuvier, *Peropus* Lay, Benn. [*sic*; later in text *Peropeas*], Taeniotus Cuvier and *Sthenopus* Richardson (genera referred by Gunther (1880) to Scorpaenidae and Cottidae), and discussed some similarities and differences, features of the new genus cited including the unarmed head, the division of the dorsal and its disjunction from the caudal, the absence of vomerine and palatine teeth, and the number of branchiostegal rays. Bleeker originally referred *Gnathanacanthus*, in terms of the taxonomic framework of the time, to the Cataphracti; subsequently, as noted by Gill (1891), in several papers he referred it to the Scorpaenidae. Of two papers devoted to that group, the first, entitled "Generum familial Scorpaenoideorum conspectus analyticus" (1876a), is stated in a footnote on the first page to be an extract from the more comprehensive *Memoir* (1876b): the diagnosis of *Gnathanacanthus* remains consistent with the original version cited above, but appears in a condensed form, given in French in the *Memoir*, in Latin in the extract. These papers are relevant to Bleeker's assessment of the status of his

TABLE 1

Comparative Morphological Features

Some comparative morphological features characterizing Tasmanian species of the six families of the suborder Scorpaenoidei (order Scorpaeniformes).

Scaleless, not enclosed wholly or partly in bony scutes	+	+[1]	—	—	+	+
Skin with numerous small papillae; velvety	+	—	—	—	+	—
Pelvice absent	—	—	—	—	—	+
Pelvic present, with fewer than 5 rays	—	—	—	—	+	—
Pelvics attached to body by sheet of tissue	+	—	—	—	—	—
Anal spines	3	3	3	0	0–1	0
Dorsal attached by membrane to caudal	—	—	—	—	—	+
Dorsal with well elevated crest on head	—	—	—	—	+	—
Dorsal origin over or in advance of eye	+	—	—	—	+	+
Number of dorsal spines relative to dorsal rays	<	>	>2×	<	<	>
Dorsal spines and rays, anal rays wholly enclosed in membrane	+	—	—	—	—	+[2]
Lower pectoral rays separate, digitiform	—	—	—	+	—	—
Lower pectoral rays branched	—	—[3]	+	—	—	—
Bony stay across cheek, usually with conspicuous spines	—	+	—	—	—	—
Pillow-like flap in front of isthmus	+	—	—	—	—	—
Subparallel lines of villi on parts of fins	+	—	—	—	—	—
Small intrusion of integument beneath upper operculum	+	—	—	—	—	—

1 One Tasmanian species, *Gymnapistes marmoratus* (Cuvier, 1829) scaleless.
2 Tasmanian species, *Aetapcus maculosus* (Gunther, 1861), *A. armatus* (Johnston, 1891).
3 One Tasmanian species only, *Gymnapistes marmoratus* (Cuvier, 1829).

genus in that they provide his interpretation of the definitive features of genera to which in the 1855 paper it is noted as being allied. In the section on Pisces in the *Zoological Record* for 1876, reviewing the second of these papers it was mistakenly stated the genus *Gnathanacanthus*, with type *G. goetzi* [sic], had not yet been described. Gunther, in ignorance of Bleeker's work, established the new genus and species, *Holoxenus cutaneus*. Concerning the status of this, "one of the most singular fishes of the Tasmanian fauna", he remarked: "At first glance the observer is inclined to refer it to the Scorpaenidae or Pediculati; but there is no bony stay for the praeoperculum, which is not armed, and the forelimb is not pediculated. Its nearest allies are evidently the Cirrhitidae, although in this family it stands isolated on account of its divided dorsal, small eye, slender pectoral rays, and almost scaleless [= scaleless] body. Placed at the end of that family, it forms a passage to the Scorpaenidae." The specific description gives A.9; but the generic diagnosis correctly notes "three anal spines". In the same year Bleeker realized the identity of Gunther's fish and his own. *Holoxenus* is the only genus of the three established for the reception of the present fish that has been provided with a species other than the type-species. Johnston (1883), after calling attention to differences in fin formulae between those of a fish before him and Gunther's specification, commented: "Should it prove to be a distinct species I propose for it the name *Holoxenus Guntheri*": by universal consent Johnston's proposal has lapsed.

The third generic name advanced, one unknown to Johnston, was *Beridia* Castelnau (1878), with type-species *B. flava*, founded on a specimen from Portland Bay, Victoria: the account includes some errors (e.g., two anal spines, a branched ray in the pectoral). Of its affinities Castelnau commented: "This new genus belongs to the *Triglidae*, and its spinous dorsal being rather less in length than the soft [the plate depicts the two fins as wholly separate without the small interposed elements], ought probably to be placed in the group *Cottina*, but the general form is very different from all the other fishes of *Triglidae*, and is more like some sorts of Gobiidae."

In the first comprehensive catalogue of Australian fishes Macleay (1881a: 438, species 138) listed Gunther's species under Scorpaenidae (without notice of Bleeker's fish), also Castelnau's (1881b: 592, species 227); subsequently in the supplement (1884: 19, species 299) noticing Johnston's suggested *H. guntheri* [*sic*] among the

Scorpaenidae. (In his table of synonymy Gill (1891: 703) gives two page numbers for each of two entries for Macleay: the second number is the species number.)

After having included in a brief summary of the progress of Vertebrate Zoology in 1878 a simple statement that *Beridia* "is the same as *Gnathanacanthidae*, long before described by Bleeker", Gill (1879: 458) later (1891) devoted a whole paper to a valuable review of the nomenclatural problems associated with the present fish; the second binomen, *goetzeei*, is there unjustifiably emended to *goetzi*, the name of the collector of the holotype, after whom the species was named, being W.J. Goetzee.

As pointed out by Gill, Bleeker's and Castelnau's plates show characters quite different from those manifest in any scorpaenids or cirritids. "The eyes are near the proximal ends of the preopercular bones, the proscapular bones are very much inclined backwards, and must consequently connect with the posterotemporals at decided angles, the pectorals are comparatively narrow and consequently the actinosts and coraccid elements must be modified, and the ventrals are subbrachial." Dismissing the suggestion from Bleeker of the presence of the normal cataphract structure in the form of a bony stay from the third suborbital across the cheek, he formally recognized for the first time the appropriateness of an independent, new family, the Gnathanacanthidae, which may be most nearly related to the congiopodids or agriopodids and the pataecids (Gill 1891: 704); suggesting in the next paragraph that these four "may even constitute a separate superfamily."

It is to be noted Bleeker himself had included *Agriopus* Cuvier, 1829, a synonym of *Congiopodus* Perry, 1811 (emended forms proposed in 1872 by Gunther, *Conchopodus* and *Coniopodus*) as one of the genera to which his novelty was related, more closely indeed than to some other genera noted by him. By early writers (Gunther 1880, Boulenger 1910) Cuvier's genus is accommodated in the very large early Scorpaenidae, with upwards of 250 species. Two members of the small family Congiopodidae (Agriopodidae), the sole family of the suborder Congiopodoidei, occur in Australia, both reported from South Australia, one also from Western Australia (and New Zealand, which has two other species). They resemble the present fish and the pataecids in being small (Australian species 0.16-0.24 m), wholly scaleless, with the forehead not greatly oblique (though, as a characteristic feature, the mouth is much produced, suggesting the vernacular name Pigfishes) and with the palatines edentulous. The pectoral, ventral and anal resemble those of *Gnathanacanthus* in size and disposition, while the dorsal, like that of the pataecids, is continuous, with spines almost twice as numerous as rays.

In Tasmania this fish has been referred to the Triglidae ("includes Scorpaenidae and Cottidae, erected into independent families in recent works" Johnston 1883), Scorpaenidae (Johnston 1891; two species of *Holoxenus* listed), Pataecidae (Lord 1923, 1927), and Gnathanacanthidae (Lord & Scott 1924, Scott 1974b, Edgar *et al.* 1982, Last *et al.* 1983). Family rankings are not noted in a paper on Tasmanian fishes by Ogilby (1897) that includes a good description of *Gnathanacanthus goetzeei*.

Deciding against the convention, virtually now universally recognized locally, of the recognition of a monotypic family Gnathanacanthidae, Greenwood et al. (1966) subsume it in Pataecidae. Examples of *Gnathanacanthus* are quite without resemblance to their figure for Pataecidae, depicting a member of that family *sensu stricto*. These authors treated the suborder Scorpaenoidei (order Scorpaeniformes) as comprising five families, Scorpaenidae (Sclerogenidae in part, including Tetrarogidae), Triglidae (Sclerogenidae in part, including Peristediidae, Peristediontidae), Caracanthidae, Aploactinidae (Aploactidae), including Bathyaploactidae), Synancejidae (Synanceidae) and Pataecidae (including Gnathnacanthidae). All five occur in Australia and all save Caracanthidae are represented in our waters. All possess features indicative of some relationship with the Gnathanacanthidae. With this family treated as distinct from Pataecidae, *s.s.*, the subjoined tabulation sets out for ready comparison some of the more obvious external features of the five groups found in Tasmania (table 1).

Genus *Gnathanacanthus* Bleeker, 1855

Gnathanacanthus Bleeker, 1855: 20. Type-species, *Gnathanacanthus goetzeii* Bleeker.

Gnathacanthus Bleeker, 1855: 31 (legend to plate). *Errore pro Gnathanacanthus.*

Holoxenus Gunther, 18766: 393. Type-species, *Holoxenus cutaneus* Gunther.

Beridia Castelnau, 1878: 229. Type-species, *Beridia flava* Castelnau.

Baridia Castlenau, 1878: legend to plate. *Errore pro Beridia.*

Gnathanacanthus Gill, 1879: 458, and 1891: 701.

Gnathacanthus (*Holoxenus*) Boulenger, 1910: 695. *Errore pro Gnathanacanthus.*

Gnathanacanthus goetzeei Bleeker, 1855

(Plates 1-3, text-figures 1-4)

Gnathanacanthus goetzeei Bleeker, 1855: 21, unnumbered plate, fig.1. Type locality: Tasmania ["Hobarttown in ostiis fluminis Derwent"].

Gnathacanthus goetzei Bleeker, 1855: 31 (legend to fig.1 of unnumbered plate). *Errore pro Gnathanacanthus goetzeei.*

Holoxenus cutaneus Gunther, 1876: 393. Type locality: Tasmania.

Gnathanacanthus goetzeei Bleeker, 1876a,b.

Beridia flava Castelnau, 1878: 229, pl.2. Type locality: Portland Bay, Victoria.

Baridia flava Castelnau, 1878: legend to pl.2. *Errore pro Beridia flava.*

Holoxenus guntheri [*sic*] Johnston, 1883: 115. Type locality: Tasmania.

Gnathanacanthus goetzeei: Ogilby, 1897: 82; Waite, 1921: 171, fig.280, and 1923: 197, unnumbered fig. (after Bleeker), and 1924: 484, pl.31; Lord & Scott, 1924: 13 (species ascribed to Black), p.86, pl. facing p.86; Whitley, 1948: 30, and 1964: 57 (species 2219); Scott, T.D., 1962: 164, unnumbered fig. facing p.164; Thomson, 1971: 130, pl.11; Scott, T.D., Glover & Southcott, 1974: 185, 358 (venom), unnumbered fig., p.185; Scott, E.O.G., 1974b: 189; Edgar, 1981: 72; Edgar, Last & Wells, 1982: 58, color pl.43; Last, Scott & Talbot, 1983: 329, 526 (venom), fig.28.17.

Gnathacanthus goetzi: O'Shaughnessy, 1876: 15; Gill, 1891: 701, unnumbered fig. (after Bleeker); Lord, 1923: 71. *Errore pro goetzeei. Gnathanacanthus goetzii*: Gill, 1891: 703. *Errore pro goetzeei. Gnathanacanthus goetzei*: Lord, 1927: 15. *Errore pro goetzeei.*

Holoxenus cutaneus: Macleay, 1881a: 438, and 1884: 19; Johnston, 1891: 31 (p.10, reprint).

Beridia flava: Macleay, 1881b: 592.

Holoxenus guntheri: Macleay, 1884: 19; Johnston, 1891: 31 (p.10, reprint).

Material

Fifteen Tasmanian examples are examined, listed below in order of increasing magnitude of standard length, mm: (a) *Ls* 125 *Lt* 162, off Eddystone Point, 137 m (75 fathoms), 19 June 1978, S. Downe, Q.V.M. Reg. No. 1978/84; (b) *Ls* 155 *Lt* 212, northwest coast, 17 March 1980, anon., 1980/5/45; (c) *Ls* 172 *Lt* 225, Middle Arm, Tamar River, 3 August 1973, S. Mountney, 1974/5/172; (d) *Ls* 190 *Lt* 258, Binalong Bay, 24 April 1973, D. Wright, 1973/5/94; (e) *Ls* 190 *Lt* 260, Bicheno, 26 February 1959, F.J. White; (f) *Ls* 192 *Lt* 250, Tamar River at mouth, 19 June 1977, J. Head, 1977/5/27; (g) *Ls* 195 *Lt* 256, off east coast, Waterhouse Island, Bass Strait, 26 May 1984, D. Barratt, 1984/5/23; (h) *Ls* 200 *Lt* 265, Greens Beach, 17 January 1980, R.H. Green, 1980/5/3; (i) *Ls* 201 *Lt* 260, Tamar River estuary, 17 September 1973, E. Porter & A.W. Hesketh, 1973/5/109; (j) *Ls* 204 *Lt* 280, off West Point, 15 December 1969, R. Burgess, 1974/5/17; (k) *Ls* 210 *Lt* 275, Eaglehawk Neck, 8 February 1975, P.R. Last, 1975/5/152; (l) *Ls* 213 *Lt* 285 3.2 km (2 miles) south of Little Swan Port, Tamar River, 1 January 1980, M. Gray, 1980/5/1; (m) *Ls* 218 *Lt* 288, off Eddystone Point, 27 December 1972, G. Allen, 1973/5/5; (n) *Ls* 235 *Lt* 315, off east coast, Cape Barren Island, Bass Strait, 2 July 1969, B. Greeno, 1969/5/28; (o) *Ls* 256 *Lt* 320, Ocean Vista, West Burnie, 2 November 1972, C. Jones & P. van der Woude, 1972/5/605. With a single exception these specimens are preserved in the collections of the Queen Victoria Museum and Art Gallery, Launceston, with registration numbers as here noted; specimen (e) from Bicheno is no longer at hand and the only measurements of it available are the 21 items recorded earlier (Scott 1974b: 190).

Figures

The account given below involves comparison with published illustrations of this species. It is expedient here to specify those examined. They comprise (a) original figure of the holotype from Tasmania, 199 mm in length (Bleeker 1855, fig.1 on unnumbered single plate), reproduced in the catalogues of South Australian fishes by Waite (1821: 171, fig.280, and 1923: 197, unnumbered fig.); (b) Castelnau's figures of the holotype from Victoria, "about seven and a half inches [0.19 m] long", of his *Beridia flava* (1878, pl.2); (c) figure published by Gill (1891, unnumbered fig.; second binomen rendered *goetzi*), of which Waite (1924: 485) noted it "was copied from that of Bleeker, but the artist, without seeing an example of the fish, straightened out some of the fin rays"; (d) in the same paper by Waite a new representation (pl.31), based on a South Australian example, 262 mm in length; (e) a painting, apparently from life, by Mrs Louisa Anne Meredith, reproduced on Lord & Scott (1924, plate facing p.86); original there noted as being in the Tasmanian Museum, Hobart); (f) a color photograph of a living example in Edgar *et al.* (1982, pl.43).

Waite's (1924) depiction, not wholly satisfactory, has been accepted as the standard figure in

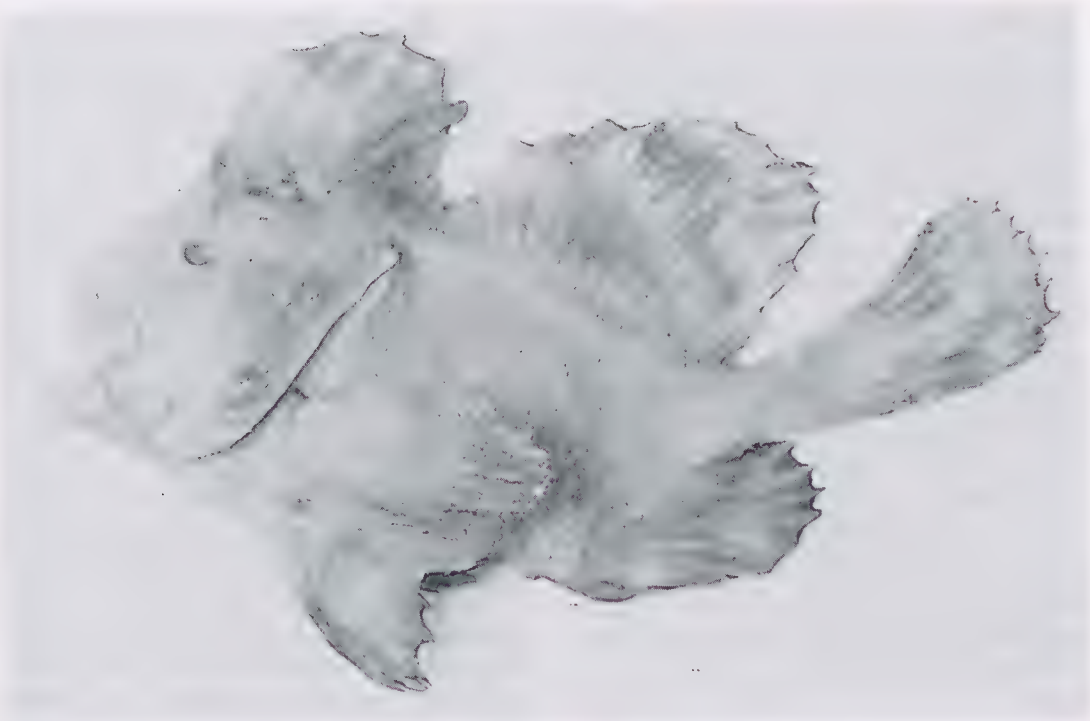

PLATE 1 — Gnathanacanthus goetzeei *Bleeker, 1855. Specimen 201 mm in standard length, from Tamar River estuary (Q.V.M. 1973/5/109). On preservation the spines and rays of the vertical fins commonly tend to slope backward: in this example the fully erect condition attainable in life is more nearly maintained, with total height, including fins, equal to, or more than, half total length. Photo: M.A. Bartkevicius.*

subsequent Australian State catalogues, e.g., Scott (1962, unnumbered on p.165), Scott *et al.* (1974, unnumbered on p.185), Last *et al.* (1983, fig.28.17), the source not acknowledged in the South Australian lists and attributed to the second of these in the Tasmanian work. In offering his figure Waite criticized those of Bleeker and Castelnau, valid points concerning the former being the shortness of the pectoral and ventral fins and the early termination of the lateral line, and concerning the latter the unacceptable sense of rotundity suggested by the shading, the complete separation of the dorsal fins, and the curiously extensive continuation of the membrane behind the dorsal and anal. Of available drawings that giving the most lively impression of the characteristic overall appearance of this fish with its large flaring fins is that of Mrs Meredith. A version of Waite's (1924) figure washed a uniform somewhat orange red has been published by Thompson (1971, pl.32). Plate 1, a photograph of a whole fish 201 mm in standard length, shows, as does a painting by L.A. Meredith reproduced in Lord and Scott (1924), vertical fins more erect than is commonly found in preserved material and depicted in illustrations. Notable morphological features, e.g., characteristic "interdorsal" region, slip of papillate integument intruding beneath operculum, arrangement of dermal papillae in files on fin, subrectangular cutaneous intermandibular pad (present in Gnathanacanthida but not in representatives of the six other locally occurring families of the Scorpaenoidei, are illustrated in several figures. Some morphological ratios are the subject of graphs.

Size

The lengths of their type specimens were noted by Bleeker, Castelnau and Gunther as 199 mm, 190 mm and 254 mm, respectively. The maximum normal size is about 0.3 m, a value accepted by Lord & Scott, Scott *et al.*, Last *et al.* Johnston noted "average total length 10 inches [254 mm]"; while a sample of 5 examples noted by the writer (1974b) showed a standard length range of 190-301, or total length of 206-320 mm. Last *et al.* reported a maximum weight of 660 g.

Distribution

Subsequent to its original recognition in Tasmania this species was successively recorded from Victoria (Castelnau 1878), South Australia (Waite 1923) and Western Australia (Whitley 1948), apparently occurring only in the southern part of the last-mentioned State. It has not been encountered elsewhere, and is thus endemic to the region between latitudes 30° and 45° S, extending along the southern coast of the Australian mainland and reaching Tasmania. It is of interest to note the Pataecidae (in which the Gnathanacanthidae is by some authors subsumed) is also restricted to Australia and is likewise primarily southern Australian in distribution, with only one of the six species recognized in the check-list (McCulloch 1929), *Pacaecus fronto* Richardson 1844 (synonym, *P. subocellatus* Gunther, 1872), ranging northwards to New South Wales and Queensland. Two members of this family, treated in the most recent review of the Tasmanian fish fauna (Last *et al.* 1983) as *Aetapcus armatus* (Johnston, 1881) and *A. maculatus* Gunther, 1881, occur, in, the former being confined to, our waters.

Head

General

The head is large, though not immoderately so, its length relative to that of fish being much the same as, or a little greater than, that commonly encountered among Tasmanian representatives of the other families of the Scorpaenoidei (most marked difference presented in Aploactinidae, in which it is less than one-third standard length). The "1/32 and 3/35 in longitudine corporis" of Bleeker relates, as is evident from his figure, to total length. Castelnau's "twice and one-third" and Waite's 2.2 in length without caudal are tolerably diagnostic. In our material head length as *TLs* is 359-460 (± 405.6 ± 6.80). The ratio of its depth to depth at hind end of trunk, approximately unity, is greater than that among the other related forms, except the Pataecidae where it is close to twice. The overall angle of entrance as estimated from figures is in general round about 80°-90°, being, at some 65°, unduly small in Castelnau's plate. In our material it is 90°-100°, smaller individuals showing some tendency towards the higher value. In specimens in which the apex is at the level of the margin of the operculum the formal angle of run is about 45°; however, in view of the approximation to equality in depth at this point and at the level of the vent, the effective angle of run is perhaps more appropriately determined measuring back from the latter point; it is then found to be near 60°.

The posterior border formed by the free margins of the branchiostegal membrane below and the operculum above is striking by virtue of its close approximation to rectilinearity from its lower extreme at the ventral contour of the fish to its upper termination located above the level of the full eye structure by a distance of from one to three times the diameter of pupil (tip shown noticeably too low by Castelnau). This straight-line course contrasts strongly with the convexity, either in the lower half or throughout the whole extent of the hind margin, in related forms. From the highest point on the posterior border the fleshy border extends briefly forward, for a distance equal to from twice to thrice a pupil diameter, in one of three main forms: (a) a simple flap with its border overall straight or very gently concave, obscurely or obviously minutely crenulate, its general course varying from an angle of about 45° to the anteroposterior axis of the fish to subparallel with the virtually horizontal dorsal profile above; (b) running obliquely down and back in its anterior portion with resultant formation there of a well-marked process, bluntly rounded, slightly broadening basally, its greatest width about two-thirds its length, the latter subequal to the pupil diameter, the border beyond this process extending forward and upward in the same crenulate linear course as that taken by the entire superior margin in the first form; (c) found in two or three individuals a structure similar to that of (b) but differing in the development at its anterior termination of a second much smaller process, the presence of which is indicated in Castelnau's plate. In that figure two long slender spines are shown running back to the bases of the processes (the text, however, noting opercules "ended by two smooth points"): no such external spines are depicted by Waite, but a strong zigzag-shaped marking in Bleeker in the relevant region may be related to them, while their general location in Castelnau is marked by two lines of shading. In our specimens there are two very slender acute subdermal spines placed as in Castelnau's figure, extending back only to the origins of the processes where these occur, their presence obscurely indicated in some individuals by slight ridges: Ogilby reported "two concealed spines", while Last *et al.* (1983: 329) observed "2 large spines on opercle, often concealed by skin."

In specimens in which the action is not inhibited by undue rigidity of the concealed spines, the fleshy border of the opercle can be carried (even, superficially, delicately rolled) forward to the level of the point of attachment, thus exposing an elongate inverted triangular region, reaching

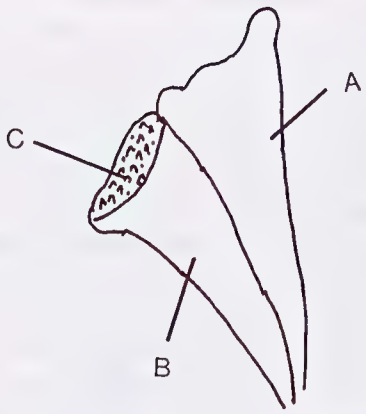

FIG.1 — Gnathanacanthus goetzeei *Bleeker, 1855. Inner surface of drawn-back operculum. A, exposing smooth membrane-invested cranium, B, into which intrudes a slip of papillate integument, C.*

down to the pectoral base, normally hidden; the hind side of this being constituted by a low rounded ridge running parallel to the border of the operculum in its normal position. This ridge is presumably indicative of the presence of the coracoid, this bone, linear down to immediately above pectoral base, thus forming "the frame or 'sill' against which the opercular and branchiostegal doors shut in closing the branchial cavity" (Owen 1866: 126); here, in agreement with the opercular form, with a straight instead of the more usual curved margin. While the greater part of this, representing the underlying cranium invested by glistening membrane, is firm and uniformly smooth, the uppermost portion presents a small subrectangular or subtriangular area (widest behind), extending horizontally for its whole length, vertically for a distance somewhat less, and being delimited above by a distinct upwardly convex fleshy rim that is continuous anteriorly with the fleshy upper margin of the operculum. This specialized region, soft to the touch, is covered throughout by the minute, closely set papillae that invest almost the entire outer surface of the fish and clearly represents an intruding element of the general integument (fig. 1).

No such invasion of the area normally covered by the operculum by an extension of the ordinary external tissue of the flank has been observed in any of the related forms examined.

In his generic diagnosis Bleeker (1885) noted occipital ridges but made no further reference to these features in his description of the holotype. In other accounts only that of Waite (1921) mentions cephalic ridges, "marked preorbital subdorsal and opercular ridges". In many specimens they are by no means strongly evident, in some practically untraceable, the degree of visual development probably being associated at least partly with mode and history of preservation. In an example left untreated for several days and then placed in alcohol (Q.V.M. No. 1984/5/23) ridges are visible as described below. Beginning below the anterior nostril, midway between it and upper lip, a narrow ridge curves back to apprach the ocular capsule at 7-8 o'clock (left side viewed); it continues upward, coming in its upper half to constitute the raised orbital rim, traceable round to about 5 o'clock. In front of this and just in advance of its origin a much broader and more conspicuous ridge, after briefly bordering the front of the posterior nostril, ascends obliquely, constituting the frontal profile here, to just below the base of the first dorsal spine, whence it continues, now much sharper and somewhat more elevated, in a slightly irregular upwardly convex arc to vertically below the fourth dorsal spine, its distance from the orbit through most of its length subequal to that from the dorsal profile. Originating immediately below the middle of the lower lip, a moderately developed ridge, in the form of a reversed L, defines the preopercular border to the level of the middle of the eye. The most conspicuous elevation extends almost linearly from middle of the hind border of the orbit to the base of the upper flap of the operculum. From near its origin one ridge proceeds obliquely down and back to meet the opercular border, itself showing some tendency to elevation, and near the middle of its length develops a short spur linking it with the subopercular ridge; a second, less pronounced, runs back about horizontally to the opercular border. From near the hind end of the ridge overarching the eye (Waite, "subdorsal") a slender ridge curves up and back more than halfway to the dorsal profile. In the generality of the specimens of our sample only two two or three best developed ridges are evident, and these may in some cases be traced only with difficulty.

It is not practicable to determine through the thick integument the disposition of the bones of the head in the suborbital and immediate postorbital region. However, examination of specimen (g), in which the skin, in the course of preservation, has behaved in a fashion markedly different from that found in all other examples, becoming thin and rigid, would appear to substantiate the account given by Bleeker in a papers published more than 20 years after the original description of his species and cited by Gill (1891: 702)) who rejected Bleeker's

interpretation, and dismissed the association with the Cataphracti, commenting (p.704) "Notwithstanding Bleeker's remarks, I must regard it as doubtful whether the normal cataphract structure is manifest, that is, whether the *third* suborbital is developed as a stay." In thus dismissing association with the Cataphracti, he was led to to establish his own new family Gnathanacanthidae.

Eye, Nares

As is commonly the case in scaleless fish, the periphery of the eye is rather ill-defined. The exposed ocular structure proper, as preserved, is quite small, circular, occasionally longitudinally somewhat elliptical, its diameter about twice that of the circular pupil; this is surrounded by a strongly elevated ring of minutely papillate tissue, the width of the annulus less than the diameter of the pupil, its external diameter about twice that of the includedstructure; this raised annulus is set in a depressed annulus of subequal width and usually well defined, commonly but not invariably being bounded externally by a distinctly raised rim; further, this whole complex is usually set in a quite ill-defined region of general slight concavity. As thousandths of standard length the diameter of the exposed eye proper is 26-42 ($\bar{x}$ 32.9 ± 1.13) with a high coefficient of variation (*V*), 13.3. Corresponding values measured to the outer margin of the circumscribing fleshy rim are 48-72 ($\bar{x}$ 64.1 ± 1.61), *V* 9.7. Bleeker recorded diameter of the eye about 6 in head length, Ogilby 4 ⅜-4 5/6, Waite 9.5 (Gunther "small", no value given by Castelnau). With use of mean values for our 15 specimens of standard length and of the two specifications of eye diameter, the ratios are 6.32, 12.32: it is evident the boundaries of the eye are subject to some differences of interpretation. The location of the eye, noted by Bleeker as well away from the forehead, is such that the distance from the middle of the pupil to the dorsal profile at insertion of the first dorsal spine, which is located vertically above it, is subequal to that from the same point to the anterior nostril, a little less than that to the nearest point on the supramaxilla, and about two-thirds that to the middle of the upper lip. The strongly convex interorbital distance is small, only about one and one-fifth times the diameter of the fleshy ocular capsule; as *TLs* 66-94 ($\bar{x}$ 77.3 ± 2.11). Ogilby reported it as smaller than (1 ¾ to 1 3/5 in) the diameter of the eye.

The posterior nostril lies level with the middle or the upper one-third of the fleshy ocular capsule (this variation being associated with differences in forehead angle), its shortest distance from it modally two-thirds the capsule diameter. Neither Bleeker's "naribus posterioribus simplicibus" nor Waite's specification, "a simple pore" is applicable to our material, in which it is in the form of a short tube, the circular or slightly elliptical free border of which is constituted by some 15-20 digitiform processes, either very closely set or contiguous basally, extending as contiguous half-columns down the side of the tube to its base; the height of the tube is some one-third, or more, of its basal diameter. The anterior nostril lies downwards and forwards from the posterior, its distance from which is rather less than that of the latter from the eye-capsule and about half its distance from the upper lip. As preserved, its appearance varies, either being much like a smaller version of the posterior nostril, but with the crenulations less developed and restricted to the hinder half of the margin, or having the form of a short column surmounted by a clump of closely packed small spheres or short broad obtuse processes; no orifice is evident (cf. perhaps, Waite's "small skinny flap"; Bleeker's "leviter tabulatis"). The anterior internarial distance is not greatly less than the interorbital distance, but slightly exceeds the posterior internarial.

Dentition

The dentition is extremely insignificant, and escaped mention by Castelnau and Ogilby. No teeth occur on the palatines, the vomer or the tongue. Moreover those present in the upper and lower jaws (in his diagnosis of *Beridia* Castelnau incorrectly wrote "none at the lower jaw") are minute, and arranged in an arc, with the width anteriorly subequal to the pupil diameter, decreasing regularly backward to close to the angle of the jaw. Closely set, they present the general appearance of a flat pavement, with in front up to half a dozen rows, smooth to the eye and to the touch of a finger; but exploration with a needlepoint encounters some discrete elevations. Castelnau (in his generic diagnosis) and Waite described the teeth as "granular", Gunther (in generic diagnosis) as "villiform", Johnston "more granular than villiform". The whole apparatus is curiously cryptic. When the mouth is opened no teeth are immediately evident, the situation clearly justifying the generic name *Gnathanacanthus*, boldly rendered by Waite (1921) "spineless jaw". In each jaw a fleshy arc of tissue, similar in form to, and only slightly smaller than, the external lip is set close to, even contiguous with, the lip; like the lip, though to a much less marked extent, it presents a tesselated appearance. When this structure is forced inwards or the lip is drawn forwards and the cleft between them is

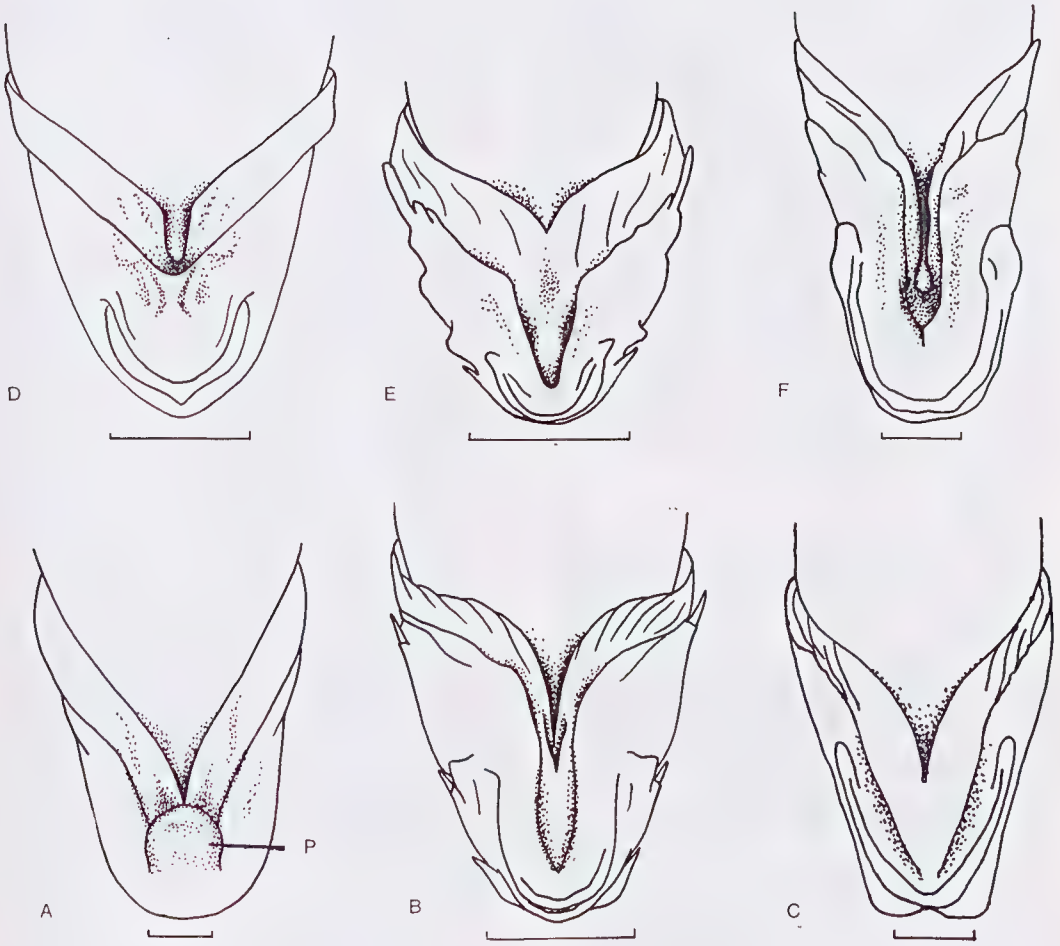

FIG.2 — Anterior ventral surface of head, showing presence in Gnathanacanthidae and absence in five other families of the suborder Scorpaenoidei of a subrectangular fleshy intermandibular pad. Bar scale equals 10 mm in each case.

A. Gnathanacanthidae, Gnathanacanthus goetzeei *Bleeker, 1855.*

B. Scorpaenidae, Gymnapistes marmoratus *(Cuvier, 1829).*

C. Triglidae, Chelidonichthys kumu *(Lesson & Garnot, 1826).*

D. Aploactinidae, Aploactisoma milesii *(Richardson, 1850).*

E. Synancejidae, Glyptauchen panduratus *(Richardson, 1850).*

F. Pataecidae, s.s., Aetapcus maculatus *(Gunter, 1861).*

widened the teeth appear, exposed on the base of the small ravine. In the upper jaw this fleshy arc develops at the middle of its outer margin a small round knob that is received into a depression on the inside of the upper lip, with which it then becomes continuous. A similar connection is developed in the lower jaw, assuming more or less clearly the nature of a ball-and-socket joint, the main process, however, in this case being developed from the lip instead of the fleshy arc. This small connector at the symphysis effectively separates the tooth-bands of the right and left rami of the jaws.

The edentulous tongue, smooth, pearly white and glistening in preserved specimens, is large, filling the whole mouth, rather massive and with the upper surface strongly convex both laterally and longitudinally. The anterior border is truncate with a variably developed mesial notch. The outline then flares out in a concave arc on either side to the greatest width, behind which the two sides continue rectilinearly with regular progressive decrease in width. From the ends of the anterior mesial notch two parallel ridges extend backward.

Snout

The general form of the snout has been described above. Its length ranges from 108 to 160 *TLs* ($\bar{x}$ 127.4 ± 16.504) equivalent to 2.6-4.0 ± 0.816 in head (Waite 3.5, Gunther "of moderate length"). Ogilby reported length in terms of the eye, "one tenth to one fifth of a diameter of the eye longer than the eye", dimensions that would appear to be unduly small; even for the larger eye value, that of the full capsule, our figures are 1.3-2.7 ($\bar{x}$ 1.96 ± 0.102, with a high value for *V*, 20.1).

Branchiostegal Apparatus, adjacent ventral surface

The branchiostegal membrane is indistinguishable in appearance from the general opercle, being minutely papillate like it and the general surface of the fish. As mentioned by Waite, the apparatus is apparently not fully concealable by the opercle. Of published accounts only that of Bleeker recorded the number of branchiostegal rays, 7; of these 5 only are visible externally, clothed inconspicuously throughout their length in the general integument.

On the ventral surface the branchiostegal membranes extend forward to the level of the angle of the rictus, ending close together, briefly in advance of the pointed tip of the isthmus, the margins of which sweep back in deeply concave curves, with the width shortly in advance of the pectoral base equal to, or exceeding, the length. At their anterior ends, level with the hind border of the supramaxilla, they are continuous with a conspicuous elevated cutaneous pad, somewhat pulpy, rather longer than wide, lying between the free inferior margins of the head here in the form of the mandible, and becoming continuous in front with the interior surface of the chin, about a full eye diameter behind the most advanced point of the latter; the sides of the pad convex, approaching each anteriorly, the hind margin convex, overlapping and concealing junctions of membranes with it.

The curious intermandibular cushion with its suggestion of being pneumatic is without exact counterpart in the Pataecidae as represented by the locally occurring genus *Aetapcus* Scott, 1936. Specimens of *A. maculatus* (Gunther, 1861) show the forward extensions of the branchiostegal arches, instead of terminating near the level of the end of the supramaxilla, continue beyond this halfway to the most advanced point of the lower jaw, terminating well apart, with, in advance of them, a small triangular area, possibly the analogue of the pad in *Gnathanacanthus*, but differing noticeably from it in being very much smaller, not continuous with the arches and, with fish viewed from below, distinctly lower than, instead of overlapping them.

The intermandibular pad of *Gnathanacanthus* is not only absent in the most closely allied family, the Pataecidae, but is not developed in any of the Tasmanian representatives of the remaining local families of the suborder Scorpaenoidei, as is made evident by the illustrations for that family and for *Gymnapistes marmoratus* (Cuvier 1829), Scorpaenidae; *Chelidonichthys kumu* (Lesson & Garnot, 1826), Triglidae; *Glyptauchen panduratus* (Richardson, 1850), Synancejidae; *Aploactisoma milesii* (Richardson, 1850), Aploactinidae provided in fig. 2.

Gills, Gill Rakers

The gills, as noted by Gunther and Waite, number four; there being a small slit behind the fourth. The numerous slender cylindrical gill filaments, minutely tuberculate, bluntly pointed, are of much the same length on all arches and throughout the greater part of the extent of each arch. The arrangement of the gill rakers is unusual. With the opercle lifted and the outer arch viewed from behind, the arch is seen to bear a definitive row of 12-13 stout rakers, of which 3-4 are on the upper limb. Waite recorded 4+8 rakers on anterior arch, noting "the first four of the lower limb are paired": in one individual in our material five are so paired, in others the duplication is evident throughout the whole or most of the lower limb, and some

TABLE 2

Gnathanacanthus goetzeei Bleeker, 1858

Lengths of fin rays and spines, specified by $L = bN^k$, rectified as $\log L = k \log N + \log b$; L length as permillages of standard length, N serial number, conventions of enumeration as in Scott (1974a). Example from inshore east of Waterhouse Island, Bass Strait, standard length 195 mm; 17th caudal ray imperfect.

Fin	Set No.	Spine or ray set	Abscissal log set	Parameters Slope (k)	Intercept ($\log b$)	r (z)	t
First dorsal	1	{I-IV}	{1-4}	0.3635	2.2857	0.99374(3.882)	35.499
	2	{IV-X}	{4-10}	-2.4421	3.9649	0.99989(4.903)	152.411
	3	{XI-XIV}	{11-14}	5.1881	-3.5715	0.99875(3.689)	28.282
	4	{X-XIV}	{10-14}	5.7227	-4.1656	0.99988(3.093)	19.032
Second dorsal	5	{1-6}	$\{1\text{-}6^2\}$	0.6093	2.0965	0.99820(3.507)	33.305
	6	{6-9}	{6-9}	-0.4323	1.8922	-0.99728(3.300)	19.148
Anal	7	{I-III}	{1-3}	0.5914	2.0897	0.99996(5.437)	115.007
	8	{1-3}	{8-6}	-0.4631	2.8774	-0.99816(3.495)	16.464
	9	{3-8}	$\{6\text{-}1^0\}$	0.1895	1.9135	0.99918(3.902)	49.463
Pectoral	10	{1-4}	$^9\text{1-4}^0$	0.3616	2.3541	0.99953(4.180)	46.203
	11	{1-5}	$^9\text{1-5}\}$	0.3413	2.3582	0.99608(3.116)	18.960
	12	{5-14}	{1-10}	0.3835	2.1941	0.99902(3.809)	63.747
Ventral	13	{1-4}	{1-4}	0.1683	2.4174	0.99714(3.274)	18.647
Caudal	14	{1-3}	{1-3}	0.7956	2.1122	0.99862(3.639)	19.018
	15	{3-6}	{3-6}	0.2036	2.3871	0.99995(5.280)	138.802
	16	{8-11}	{3-6}	0.3506	2.3481	0.99401(2.904)	7.204
	17	{11-13}	{1-3}	0.65510	2.2030	0.99970(4.406)	40.946

supernumerary rakers may occur also on the short upper limb. The rakers on the lower limb are set fairly close together, the interval between them subequal to their length; each is in the form of a short cylinder having a rounded top or expanding terminally into mushroom-like aggregation of very numerous minute pointed processes, the rim of the pileus tending in some individuals to extend, especially inferiorly, beyond the supporting column. (Rakers with a similar distal structure occur in the pataecid genus *Aetapcus*, but here the microscopically spinulate dome-like formation constitutes virtually the whole raker, the domes being contiguous.) The members of the auxiliary row may be opposite but are more usually set alternately between those of the primary series; the latter being set about normal to the arch, the former tending to point inward.

Lateral Line

The lateral line is not prominent and in some individuals is detected only with difficulty, particularly posteriorly. Bleeker observed "antice tantum conspicua", and his figure depicts it as ending abruptly, after a somewhat sigmoid, chiefly downward course, below the first dorsal ray on the upper one-fourth of the flank. Illustrations by Castelnau and Waite trace it throughout its full course, with its termination level with the ends of the dorsal and anal membranes, the former author having it running horizontal for two-thirds of its length, then curving down strongly, the latter showing it, as in his description, "leaving the profile below the soft dorsal", terminating "above the middle of the peduncle", level with the vertical fin terminations. Our specimens exhibit considerable variation, its course at times differing somewhat on the two sides of the same individual. The specification provided by Waite, with origin over the opercle close below the dorsal edge, is appropriate to some of our examples, while some have the general course virtually rectilinear, with others showing much more convexity in the anterior section than depicted in any illustration. The end of the line while modally occurring just above the middle of the origin of the caudal peduncle may be located much higher, about five times as distant from the ventral as from the dorsal profile here. Some 12-15 low rounded tubercles are found back to about the level of the vent; the number behind this being difficult to determine, the sum perhaps about the same as in the anterior section. In a few cases the tubercles

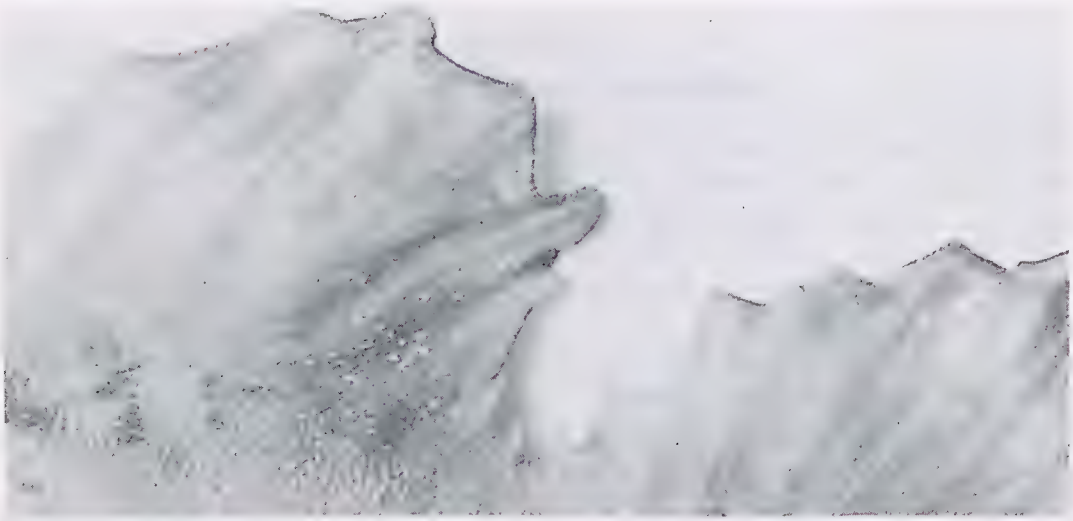

PLATE 2 — Gnathanacanthus goetzeei *Bleeker, 1855. The "Interdorsal" region of the specimen depicted in plate 1, showing the rudimentary of vestigial spinous elements, wholly invested in membrane, that are a characteristic feature of the species. Photo: M.A. Bartkevicius.*

may be connected by a low ridge, with the resultant impression of a continuous line.

Fins

In Part XIX of these contributions (1974a) it was noted that in five species, belonging to as many families, a simple relationship, consistent within the species, subsists between the lengths of the fin spines and rays and their sequential distribution along the base of the fin. The size component of the size-position pattern is commonly the logarithm of the length, while the position component is commonly the logarithm of the natural number indicating the sequential relation, in linear series, of the radial item; this natural number series, 1,2,3..., sometimes proceeds from the initial item caudad, sometimes cephalad. Thus $L = bN^k$ or $L = bN'^k$, where L = length of radial element, N = the serial number of the ray counting caudad, N' = the serial number counting cephalad, while b and k are constants. Rectification of these exponential relations, yielding $\log L = k \log N + \log b$ and $\log L = k \log N' + \log b$, affords a ready visual comparison between samples of the parameters, k being represented by the slope of the resultant straight line, and $\log b$ by its intercept on the ordinate axis. The statistical significance of the line, indicated by the value of t, can be read directly from the rectified equation, as also can be estimated values of variates it yields. In contributions following Part XIX, published a dozen years ago, numerous instances, relating to a wide range of families, have been reported in which this logarithmic length-number relation of radial elements has been found to obtain.

In these results, figures in one or more parentheses preceding "on" specify the spines or rays, while the figures following are the natural numbers with which the radial element numbers are associated for graphing: in both cases the logarithmic values of the lengths and the serial numbers are employed. "First" (= total spinous) dorsal, {I-IV}, {IV-X}, {XI-XIV} on {1-4}, {4-10}, {11-14}: second (= rayed) dorsal, }1-4}, {4-9} on {9-6}, {6-1}: anal, {I-III} on {1-3}; and {1-3}, {3-8} on {8-6}, {6-1}: pectoral, {1-5}, {5-14} on {1-5}, {1-10}: ventral {1-4} on {1-4}: caudal, {1-3}, {3-6} on {1-3}, {3-6}; and {8-11}, {11-13}' on {3-6}, {1-3}: (7th caudal ray imperfect). Data for an example of *Gnathanacanthus goetzeei*, specimen (m) of present material, were reported in Part XX (1974b: 192,193).

The parameters of the rectified equations and indications of their significance and predictive reliability, are set out in table 2. Specimen (g) thus investigated proves to be not at all points typical, and, while the subsistence of a length-number relationship remains, some differences in detail are encountered in other examples; further, it would appear that a descendant section of a fin that may be regarded as constituting a section with a negative slope in an overall graph for a fin may alternatively be treated as a separate graph using inverse numerals and having a positive slope.

Dorsal Fins

The occurrence of, as it were, a tertium quid intersposed between what would normally be recognized as first and second dorsal fins, the elements of which may conceivably be assigned to either of those fins, or to neither of them, constitutes a quite exceptional feature of this fish. While a first-glance assessment might accept the existence of two separate dorsal fins (the first of spines only, the second of spines and soft rays), and of these two only (an assessment explicitly made by Castelnau, with such a situation depicted in his plate), closer inspection shows the termination of the normal first dorsal is followed by several small processes, ranging from short to barely recognizable, those projecting only 1 or 2 mm terminating as fleshy knobs, barely distinguishable at sight from the smaller fleshy villi covering the general surface of the fish, but found to extend rigidly beneath the soft integument and to include concealed spines (plate 2); beyond these minor processes there are several well-developed spines, increasing in length caudad, that are fully incorporated in a common membrane with the 9-10 soft rays of the putative second dorsal.

The dorsal formulae as reported in the literature present a highly unusual (possibly unparalleled) diversity. Attention was called by Johnston to marked differences between his fish counts and those of Gunther, differences that provided the basis for his tentatively proposed name of *Holoxenus guntheri* [*sic*]. In the classic paper in which the identity of all three genera, *Gnathanacanthus, Holoxenus* and *Beridia* was first recognized, Gill (1891: 702) provided a table of the radial formulae as presented by the four authors involved, and discussed some discrepancies. Some of the published reports make no typographical distinction between counts of spines and rays and some give counts in words: to facilitate comparison they are here rendered with observance of the conventional use of roman numerals for spines, arabic for rays. Published formulae include: xxi, 11 (Bleeker); viii, 10, in generic diagnosis, or vii, 10, in specific diagnosis and in plate (Castelnau); viii, iii, 10 (Gunther); xii-xiii, 9-10 (Ogilby); viii, v, 10 (Johnston); viii, v, 9 (Waite); vii-viii, iii-v, 10 (Lord & Scott 1924); vii, iii, 10–11 (Scott 1962, and later version of Scott *et al.* 1974); vii-viii, iii-iv, 9-10 (Scott 1974b); x, 10-11 (Last *et al.* 1983). Thus the combination of individual variation in fish and individual variation in observer leads to the formulae being as numerous as the sources cited. In the present sample of 14 individuals the counts are as follows: spines of first dorsal 7 (13 cases), 8 (1): other spines, small, normally developed, 1, 4 (3 cases), 2, 4 (6), 3, 4 (4), 3, 3 (1); rays 9 (5), 10 (9); total number of elements 22 (3), 23 (10), 24 (1); cf. reported totals of 17-23 (or, disregarding Castelnau's clearly incorrect count, 19-23), with 23 as mode.

The significance of the fin structures occurring along the dorsal profile of this species is problematical; the most obvious interpretation being that they represent an otherwise conventional continuous dorsal fin (such as that in the Pataecidae, Aploactinidae, Synancejidae, some Scorpaenidae; not Triglidae) that has suffered a collapse, or even a local disjunction, near the middle of the spinous section. Such an interpretation receives support from the fact that it is possible in some cases (in view of the irregularity among the small spines, not in all) to treat (table 2) the whole spinous complement as a graphic continuum (even though the line consists of several sharply angled components). Further, the occurrence in what would be a second dorsal of 4-5 well developed spines, is in marked contrast to the pattern of 0, 1 or 2 in most species of fish. However, if such a process has taken place in a wholly continuous pataecid or aploactinid type of fin, it would be necessary to recognize it has been followed by a curious adjustment in the lengths of some spines leading to the establishment of fins comparable in general formation to independent first and second dorsals, with the spines of the descendant edge of the former and those of the ascendant edge of the latter having lengths that in a loglog plot are functions of low natural numbers, a relationship that would not be expected to be characteristic of an unmodified uninterrupted fin of *Aetapcus* or *Aploactisoma*. It is to be noted moreover that a serial number-length pattern of spines is found also in the anal, the two fins as a whole coming close to being a pair. With the interpretation of a modified single, continuous dorsal here suggested, the small structures immediately behind the present first dorsal would be accepted as vestigial: if it were shown they are rudimentary, the whole dorsal complex would appear *sui generis*.

Originating at or very close to the level of the eye the first dorsal extends to about an eye-capsule diameter beyond the operculum (not far enough back in Castelnau), the membrane continuing down and back in a concave arc from tip of last spine, usually becoming more or less obscurely continuous with the low membrane of the first low spine. The membrane as a whole exhibits a moderate degree of emargination; as an individual variation it may be straight betwen the spines, giving the

fin a rather curious squared-off appearance. The base ranges from 208 to 349 *TLs* units ($\bar{x}$ 294.2 ± 11.26), the coefficient of variation thus being high (*V* 14.3). The hindmost point of the fin may be level with, or somewhat in advance of or behind, that of the anal, ranging from 10 TLs units short of to 64 units past the level of the hypural joint. The spines are rigid, straight or, especially the first, slightly proconvex: in our material none exhibit the degree of curvature depicted by Bleeker and by Waite. They are normally wholly enveloped in thick integument, though when the tip is touched the spine is clearly felt; when exposed it is seen to taper through some distance to a needle-point. A fin margin with an arc of acute projections such as is commonly illustrated (spine points conspicuous in Waite) is purely a post-morten feature. Scott *et al.* and Last *et al.* note the spines can inflict a painful wound, the former reporting a pricking that caused extreme pain with loss of consciousness, associated with discoloration and swelling of the hand, the swelling being still present two weeks later.

The dorsal spines regularly increase in length from first to third, exceptionally [specimens (d), (g)] to fourth. Lengths of some of these as fractions of another are noted by several writers; however, a precise specification of relative magnitudes is afforded by the relation $\log L = bN^k$, where *N* is serial number of spines {1-3}, exceptionally {1-4}. The three dorsal spine lengths as reported for the specimen dealt with in Part XIX were absolute, in millimetres. With lengths treated as millesimals of standard length, the rectified equation is $\log L = 0.4365 \log N + 2.5267$, giving *r* 0.99930 (*z* 3.979), *t* 26.783; percentage deviation of estimated from measured lengths 0.3-1.0(0.6), $\bar{x}$ 0.68. Table 2 sets out specifications for this and for length-number relations of other fins for specimen (g), *Ls* 195 mm, one of two exceptional individuals with longest spine fourth. Mean lengths of spines {1-3} in our other material are 183.6, 244.8, 275.4 *TLs*: for the best straight line of length-number relation the slope is 0.3740, intercept 2.2671, giving *r* 0.99617 (*z* 3.128), *t* 11.389; percentage deviations 0.8-2.1(1.3), $\bar{x}$ 1.39.

In the calculations for specimen (g) in table 2 the three small spines beyond the seventh spine of the patent first dorsal were treated as part of that fin. In view of the variation of the small spines from 1 to 3, in the consideration of the whole sample spines for the formal dorsal considered have been restricted to the initial seven, the descendant series thus being {4-7}. These four spines decrease regularly caudad, mean lengths (13 specimens) being 233.2, 213.2, 153.6, 91.5. Logarithmic lengths plotted on logs {1-4} give a straight line significant at better than P 0.01 (*t* 11.154); slope 0.6914, intercept 1.9710, *r* 0.99206 (*z* 2.763); percentage deviations 1.7-6.2(4.6), $\bar{x}$ 3.78.

Not only are the relative lengths of the spines in the individual fish a function, as shown above, of their ordinal position in the fin, but, further, they are found to vary among individuals as a function of overall length. This relation is considered below in a section on differential growth.

The second dorsal, treated as represented by the last four spines (one specimen 3) and the 9 rays (5 cases) or 10 rays (9 cases), originates about over the vent and ends directly above, or marginally before or behind, the end of the anal, being attached to the peduncle by a short membrane, the end point of which is modally near that of the adpressed ray; however, marked individual variation occurs and the backward extension may be considerable, though nothing matching the long sweep depicted in Castelnau's plate has been observed. The area of the membrane of the whole fin, shown as less than that of the anal by Bleeker and greater by Castelnau, is modally somewhat less, in several specimens somewhat greater.

The four significant spines have been considered above. The rays are all simple, rather stout basally, either essentially rectilinear or exhibiting a slightly proconvex curve that may become marked in the short terminal section extending beyond the adjacent emarginate membrane, this emargination moderate (height of arc less than, commonly half to two-thirds, base), much the same as in anal, caudal, ventral, greater than that usual in first dorsal and pectoral (somewhat greater than in Waite's figure; scarcely indicated by Bleeker). The hindmost point of the adpressed fin approximates the level of the hypural joint, ranging from 2.4 *TLs* units in advance of this to about 60 behind it.

Primarily owing to the presence of some imperfect rays, measurements of the full dorsal series are available only for 7 individuals with 10 rays and 4 for those with 9; in 6, 3 of these lengths increase to fourth ray, in specimen (g), *Ls* 195, the data for which are set out in table 2, exceptionally to sixth. For the 6 inndividuals with fourth ray longest, rays {1-4} are specified by $\log L = 0.2039 \log \{1\text{-}4\} + 2.4455$; *r* 0.99983 (*z* 4.864), *t* 76.616; percentage deviation 0.1-0.2(0.2), $\bar{x}$ 0.02. For rays {5–10} on logs {1-6}, the slope of the best straight line is 0.7364, the intercept 1.9724; *r* 0.99748 (*z* 3.443), *t* 28.128; percentage deviation 0.4–5.0(4.0), $\bar{x}$ 2.8. In an earlier contribution (1974b: 192) rays {5-10} of the specimen here listed as (m) were dissected into two sets, {5-7}, {8–10}, each plotted

on log {1-3}; pooled as for above sets on logs {1-6} they still show a satisfactory correlation of r 0.99714 (z 3.274), yielding t 26.398.

Anal Fin

The large anal fin, opposite and subequal in size and similar in general form to the second dorsal, consists of 3 spines and 7-9 rays, modally 8, the 7 being found in one individual only in our material (only 2 spines were reported by Castelnau and by Waite; in his species description Gunther has simply "9", but in the generic diagnosis notes "three anal spines"). They are tolerably stout but normally quite invisible, wholly enclosed in thickish integument. The ranges and means of the lengths are 70-116, 90.16; 106-184, 139.24; 137-216, 176.85. The relative length, TLs, of each is inversely correlated with length of fish (see section on differential growth below).

When the logarithms of the mean spine lengths are plotted against their serial numbers, a very good straight line with r 0.99967 (z 4.359), t 3.801 results; the slope is 0.6147, the intercept 1.9560; estimated lengths differ from measured only by 0.2-0.6(0.4), $\bar{x}$ 0.41%. For the single individuals of Part XX and of table 2 here, the slopes are 0.6153, 0.5806; intercepts 2.2340, 2.0283; r 0.99969, 0.99784 (z 4.400, 3.414), t 40.158, 15.191; percentage deviations 0.4-1.0(0.6), $\bar{x}$ 0.66; 0.9-2.5(1.9), $\bar{x}$ 1.75.

The simple anal rays are similar in character to the dorsal rays and in general subequal in size to them. They modally increase in length to the fourth (two exceptions, one being reported in able 2, only to third). For seven sets of fins with eight rays the logarithmic lengths of {1-4} and of {8-5}, each on logs {1-4} yield highly significant straight lines. Slopes are 0.2138, 0.7104; intercepts 2.3798, 2.0435; r 0.99947, 0.99900 (z 4.118, 3.805), t 43.611, 31.611; percentage deviation of estimated from measured lengths 0.0-0.6(0.4), $\bar{x}$ 0.29, 0.1-2.3(2.1), $\bar{x}$ 1.32.

Pectoral Fin

The pectoral fin is large (as pointed out by Waite, shown unduly small by Bleeker), extending when adpressed from the level of the vent to below the first anal ray, modally about to anal origin. When fully expanded it presents a broadly rounded fan, its lateral extent up to four-fifths its longitudinal, subequal to postorbital head, with the degree of emargination of the membrane of the same order as that found in the dorsal fins; the margin is depicted by Bleeker as entire. It originates shortly behind pelvic origin at 349-364 ($\bar{x}$ 390.4 ± 7.560) permillages of standardlength. The characteristic ray count is 11; in one specimen (b) 11 in one fin, 10 in other, in one specimen (d), 12 in both fins, and 14 in (g), ray lengths of all fins of which are recorded in table 2. All rays (like those of the other fins) are simple, Castelnau's "one upper branched ray", figure showing division near middle of length, presumably being a misinterpretation of the fact that the two upper rays are either, as described by Waite for his individual, conjoined at the base or are at least closely apposed there. It has been observed (Scott 1974b: 190) "the partial concealment of the rays by thick membrane may lead to there being the appearance of a single ray bifurcated in its distal two-thirds or so". The rays are wholly enclosed in thick membrane, the tip differing notably from the more or less pointed form found in the vertical fins (including the caudal) in being rounded or distinctly spatulate, the short distal expansion in the latter case often with a minute medial cleft or notch; the whole with at times something of a ruched effect. The broad fin base, its width subequal to the direct distance of the eye from the upper lip, is set low, its distance from the ventral profile below it one-third its base or a little more.

The pectoral rays modally increase to the fifth, the fourth and sixth often not greatly shorter. From table 2 it is seen that the exceptionally large total of 14 rays in the specimen there dealt with is divisible into two sets, the initial {1-5} and the following {5-14}, with the sets intersecting, such that on a loglog plot on {1-5} and {5-10}, second set with rays counted cephalad (N′), yield highly significant straight lines — a significance higher than that for {1-5} being found for {1-4}. To provide data for a specimen with the modal complement of 11 rays, comparable equations have been calculated for comparable sets in specimen (n), *Ls* 235, the second set here comprising only rays {5-11}, both sets, as before, being intersecting. For {1-5} $\log L = 0.2383 \log N + 2.3803$; r 0.99523 (z 3.012), t 17.665; for {5-11} $\log L = 0.4395 \log N' + 2.1837$; r 0.99828 (z 3.051), t 38.078. Percentage deviations of estimated from measured lengths are 0.7-2.2(1.3), $\bar{x}$ 1.22; 0.4-2.6(2.5), $\bar{x}$ 1.41. Lengths (14 specimens) of first ray are 176 (next lowest 226)-310, $\bar{x}$ 267.8 ± 10.522; of last ray 162-248, $\bar{x}$ 209.1 ± 8.451, of longest ray 285–407, $\bar{x}$ 353.6 ± 8.716, the last measurement, with V 9.2, showing the least variation (cf. 14.7, 14.9). Relative (*TLs*) ray lengths of individuals show some indiction of being inversely correlated with size of fish (see further, below).

Ventral Fin

The large ventral, with 1 spine and 5 rays, is inserted at 264-393, ($\bar{x}$ 320.7 ± 8.125) *TLs* of the

length, the mean value being 1.22 times the mean value for length to pectoral insertion. The fin as depicted by Bleeker is much too small; in Castelnau's plate only four rays are evident, though the text correctly gives five. The fin extends, as reported by Ogilby, from just before the vent to just beyond the origin of the anal, its hindmost point normally being slightly in advance of that of the pectoral. A striking feature of the ventral (reported among early observers only by Gunther, and not mentioned in the recent Tasmanian catalogue by Last *et al.*), without parallel in other members of the suborder Scorpaenoidei (no ventrals in Pataecidae), is the presence of an extension of the fin membrane behind the postaxial ray, joining the fin to the body and extending as a variably developed slip about to the level of the vent and continuing as a ridge, becoming progressively obsolescent, about to the level of the anal origin; the degree of development subject to some individual variation but with the anterior portion always clearly evident. The nature and size of the fin elements have received some notice in the literature. Before these are looked at it seems expedient to set out the data provided by the present material.

For 12 specimens the ranges and means of the lengths of the spine and rays are as follows, the ray taken as the first being that furthest from the spine (nearest to mediolateral line of fish; postaxial), in accordance with the convention proposed in Part XIX (1974a: 238): spine 143-192 ($\bar{x}$ 166.3 ± 6.411), ray 5224-308 ($\bar{x}$ 265.9 ± 10.202), ray 4238–333 ($\bar{x}$ 283.9 ± 10.588), ray 3219-321 ($\bar{x}$ 271.5 ± 9.582), ray 2200-292 ($\bar{x}$ 224.7 ± 11.984), ray 1126-262 ($\bar{x}$ 156.3 ± 13.604), the minimum value being provided in each instance by specimen (k), *Ls* 210. In an excellent account of two specimens, length (apparently total length) 270, 280 mm, part of a Tasmanian collection later destroyed by an accident, Ogilby reported the spine as 1 2/3 to 2 in the length of the longest ray. In good agreement the ratio for 12 specimens is 1.42-1.79 ($\bar{x}$ 1.65 ± 0.035). He stated "the margin of the fin is either rounded or subacuminate owing to the prolongation of the two outer rays". As is seen from the figures above for our material these two rays, though the longest elements of the fin, do not on the average greatly exceed the adjacent ray (in our notation the third), ray 4 may in individual cases be one-seventh longer than ray 3. Waite's statement that the second and third rays are equal to the fourth and fifth is not valid for our material. Waite further noted the stout spine (completely concealed in membrane) "is equal to the second of the anal". In our material the spine of the ventral is larger on the average than the second anal spine (166.3, 139.2): however the ranges overlap (143–192, 106–184) and in several cases the lengths are close to equality.

It has been reported in these contributions that in a wide range of species it is found that in a loglog plot the lengths of rays {1-4} yield a statistically significant straight line on their serial numbers. Using mean lengths for 12 fish the equation is $\log L = 0.4562 \log N + 2.2026$; r 0.99231 (z 2.773), t 13.767; percentage deviations 2.0–3.7(3.1), $\bar{x}$ 2.84. A notably different slope of 0.1683 is found (table 2) for specimen (g). For the individual noted in Part XX (1974b), specimen (m) of present series, with dimensions (there cited in millimetres) expressed as *TLs*, the equation is $\log L = 3427 \log N + 2.2224$; r 0.99915 (z 3.884), t 34.371; percentage deviations 0.0–1.2(0.7), $\bar{x}$ 0.62.

Caudal Fin

The well developed caudal resembles all the other fins in having all the rays simple and wholly enclosed in membrane. In 12 individuals the rays number 12(6), 13(2), 14(4): the number reported by most writers is 12, though Last *et al.* give 10-12. It ranges from barely to moderately convex, never among the present specimens quite reaching the degree of convexity shown in the figure of the type, and differing further in the junction of the distal with the lateral profiles being not obviously continuous. The fin presents two distinct moieties, the innermost rays of which are separated basally by an interval from two to three times as great as that between each of them and the next outward ray. Though the overall hind margin is close to symmetrical, the short outer rays, which are not involved in the main sweep of that border, differ in length, that of the uppermost ranging from 152 to 291 ($\bar{x}$ 234.3 ± 12.62), that of the lowermost from 119 to 292 ($\bar{x}$ 180.8 ± 16.35). Both these dimensions fall well short of that of the longest ray, 349.1 ± 10.33, this length being achieved by one or both of the innermost rays of the moiety. With length to base of caudal (*Ls*) taken as 1 000, total length is 1 250-1 373 ($\bar{x}$ 1 324.3 ± 8.76); the set being compact with V 2.6. Ogilby's statement that the fin is subequal to the pectoral is valid for most of our sample, being inapplicable, however, to all the smaller specimens, the smallest individual having its pectoral half as long again as its caudal. His ratios for fin in total length are 3 5/9-3 2/3: our wider range is 2.8-5.0, with mean 4.0 ± 0.140. The fin appears to be noticeably flexuous, the color photograph of a living fish in Edgar *et al.* apparently depicting the lower portion as sweeping in front of the rest.

In the specimen from Bass Strait (g), *Ls* 195, a difference in preservation procedure has led to an end result quite different from that found in the other examples, the thick opaque integument enveloping the rays in this fin having become sufficiently transparent for the transverse septa of the fin rays to become readily visible. These are set exceptionally close together, with, in a ray 1 mm in diameter, 25-30 in 10 mm of its length. Though they are not so evident in rays of the other fins, it is possible to determine a similar approximation obtains here also.

Integument

The soft velvety skin that suggests the vernacular name of "velvetfish" (sometimes rendered as two words), or, in distinction from the locally occurring aploactinid velvetfish *Aploactisoma milesii* (Richardson, 1850), red velvetfish, envelops the whole fish including the fins, and, as pointed out by Waite, even the branchiostegal membrane and its rays. It is highly pliable and is capable of being gathered up to some extent between the fingers, exhibiting, however, less general looseness than is often encountered in preserved examples of the pataecid *Aetapcus*. It bears everywhere minute closely set soft villi which cover the lips, continuing briefly into the buccal cavity, and extend over the whole of the ocular capsule other than the actual eyeball; as noted above a small patch intrudes beneath the upper angle of the operculum (fig. 1). Upon superficial inspection these all appear to be closely similar; on more careful examination they are found to exhibit some variety of form, the outline most commonly circular, sometimes elliptical, sometimes with an otherwise circular circumference briefly rectilinear, the general form either dome-like or mammiform, at times with a distinct mammiliary termination. On the flank of an average-sized fish the larger villi have a basal diameter of a millimetre or a little less but there is marked variation in size, scattered among these being many only half as large or less, while examination with a lens reveals between the bases of the others what may be described as a secondary series with a diameter of about 0.1–0.2 mm. All sizes are distributed irregularly, with a modal number of the larger series on most parts of the fish in the vicinity of 70 cm^{-2}, this number being double or more on parts of the head, the villi there being smaller than elsewhere and all of one size, there being among them no small secondary elements. Though closely set, in some areas at varying in others at tolerably even distances apart, they are seldom, if ever, contiguous.

Though on the head, trunk and tail the villi are normally scattered irregularly, on the left side of one individual examined (barely on the right) in an area above the middle of the anal base, extending halfway towards the dorsal profile, they form more or less definite subvertical lines. In marked contrast to the usual condition on the body, on the fins they are generally, though not invariably, in definite straight lines, 4-5 such lines running along a pectoral ray, round about 15 on the membrane between adjacent spines of first dorsal (plate 3). These lines may extend the whole distance between the proximal and distal borders, in which case they are subparallel to the spine or ray, or they may become apparent only in the outer half or more of the fin, then running somewhat obliquely upward and backward. At times the intervals between successive villi are elevated, resulting in a continuous ridge surmounted by closely set projections. This linear disposition on the fins is not clearly evident in published figures and appears not to have attracted notice in the literature.

Coloration

The coloration has been reported by most early authors as being uniform, though of differing hues ("corpore pinnisque fuscente-rubris immaculatis", Bleeker (1855); "entirely of a beautiful orange colour", Castelnau (1878); "head and body scarlet, paler below", with fins mainly similar but darker, Waite (1921); "rich red or reddish purple", Lord & Scott (1924); "reddish, sometimes with slight orange tinge", Scott *et al.* (1974). Departures from uniform coloration are noted by Johnston, "sometimes more or less marbled with yellow"; the only available color photograph, that of Edgar *et al.* (1982), exhibits the pale yellow reticulation stated by Last *et al.* often to be found on the sides. Of the type of his *Holoxenus cutaneus* Gunther wrote, " uniform whitish (in spirits)". This is applicable to all our material save specimen (g), which was left unprocessed for some time before being placed in alcohol: it is largely orange, somewhat dusky in parts, with the anterior portion of the head yellowish; the fins largely greenish, the pectoral somewhat yellowish green, the ventral and pectoral with some deep red, the vertical fins with yellow or orange longitudinal stripes. Coloration of another specimen (present e) examined shortly after capture was reported in detail by Scott (1974b). Castelnau noted of the holotype of his *Beridia flava*, "Having received it in a dry state, I put it in warm water to extend parts of the fins; the water became almost immediately of the same beautiful yellow colour of the fish". The color is

PLATE 3 — Gnathanacanthus goetzeei *Bleeker, 1855. Part of first dorsal and of head, showing disposition of dermal papillae; arranged in parallel lines on the former, irregularly dispersed on the latter. Photo: M.A. Bartkevicius.*

extracted also by alcohol; if the fish is contained in a white plastic dish the walls take a stain very difficult to remove. Noting the reports on coloration and the evidence that the pigments are soluble, Gill remarked that "discrepancies as to the shade of colour are of little account".

Relative Growth

General

With authors having in general only one of two specimens [Scott (1874b) five] at their disposal, no study of differential growth throughout ontogeny has hitherto been attempted. With 11 of the 15 individuals covering only the restricted standard length range of 172-218 mm, showing the small coefficient of variation of 6.5, the present material is by no means ideally adapted for the investigation of relative growth. Two approaches to the problem are here adopted. In cases in which the correlation of the relevant item with Ls obtains, the whole sample (or so much of it as is available, allowing for damaged parts) is used for the determination of statistical significance by calculation of *t*. The presence of two small individuals of *Ls* 125, 155 and of two large individuals of *Ls* 235, 256, with each set tolerably well distanced from the rest of the series, suggests the comparison of these two pairs, the means of which are here denoted by L and H [low and high]. With this comparison there is considered a further one, the direct comparison of the mean of a subsample LL, consisting of 7 specimens of *Ls* 125-195, with the mean of subsample HH, consisting of 5 specimens of *Ls* 200-256. In general it is not appropriate to divide the material into two subsamples with subequal numbers of variates and proceed to the standard test for the difference of small samples (Simpson & Roe 1939): with the subsample made of reasonable size by the inclusion of the two extreme values with the remaining five or six intermediate values the magnitudes of d_1^2 and d_2^2 will tend to lead to a very large denominator, and hence to an unacceptably

low measure of significance. While the subsample procedure here adopted cannot be counted on to provide a formally significant test of difference, nevertheless a marked divergence between L and H, particularly if supported by a discrepancy of like sense between LL and HH, may well point to the more or less probable existence of correlation.

Fin Origins and Terminations

When lengths to fin origins and terminations as found in the largest two specimens, *Ls* 235, 256 mm, are plotted against those found in the smallest two, *Ls* 125, 155, two straight lines are formed. One, involving the first and second dorsal and the pectoral and ventral origins, together with the termination of the first dorsal, has a slope of 1.33, intercept -61.49, exhibiting a correlation of *r* 0.97778 (*z* 2.244) representing *t* 13.193 [in the calculation of the equation specimen (a) was paired with (n), (b) with (o)]. Caudad of the first dorsal origin, where the mean value for (a), (b) is 164 and that for (n), (o) 148.5, the lengths to origins and terminations of the fins exceed those to the dorsal (by 10-105, $\bar{x}$ 48.5 *TLs* units); the relative lengths to accepted morphological loci within this domain thus increasing with the length of the fish. To the contrary in the second line with slope less than unity (0.855), the values for the smaller fish are in excess of those for the larger; this line has *r* 0.99713 (*z* 3.432); *t* 28.593. Hence on these findings the anterior portion of the fish increases, while the posterior decreases with age. However, it is to be noted that extrapolation of the second line to include length to head yields the very high correlation of *r* 0.99887 (*z* 3.738), *t* 58.573, with the formally possible consequence that the relative growth of the head stands apart from that of the insertions and terminations of the anterior fins, being linked with those located in the posterior part of the body.

Fin Spines and Rays

The lengths of the radial elements of the fins as a function of the length of the fish have been examined for all fins. In each instance the sum of a set of rays is dealt with, this sum being that of all elements of the fin (as with dorsal rays), of the elements of a distinct section of a fin (spines of ascending edge of first dorsal), of a selected ray (largest) or of a selected group of rays (first, last, longest). The striking fact emerges that in every case the value of the correlation coefficient of spine or ray length with standard length is negative. In seven instances the t value represents formal statistical significance at P 0.05 or better. These are specified in table 3. Other negative correlations that do not yield such a definitive result by virtue of differences between L and H and between LL and HH suggest probable correlation are noted below, numerals in round brackets noting the number of specimens involved when this falls short of the full complement. For each set there are given *r* (*z*); *t*; L, H; LL, HH in that sequence. Dorsal spines {4-7} (12): -0.4508 (-0.486); 2.117; 775, 622, 784(6), 658. Dorsal rays {1-10} (7): -0.7305 (-0.875); 2.214; 2774, 2642(1); 2730(3), 2593(4). Anal rays {1-8} (7): -0.4341 (-0.465); 1.077; 2012, 1754(1); 2025(4), 1890(3). Anal rays {first, last longest} (12, omitting (b)): -0.5376 (-0.601); 2016, 756(1), 614(1); 730(6), 668(6). Pelvic {spine, 5 rays} (12): -0.3519 (-0.368); 1.187; 1398, 948(1); 1466(5), 1309(7). Caudal rays {first, last, longest} (13): -0.2542 (-0.260); 0.872; 678, 620; 798(5), 712.

Other Correlated Features

Some correlations involving features other than those dealt with above are here noted. Where the magnitude of r is not sufficient to denote formal significance, as is mostly the case, only the values of L, H, LL, HH are cited, and these only when the discrepancies between L and H and that betwen LL and HH are of the same sense: dimensions as *TLs*.

Head 418, 378;411, 401. Trunk in *Ls* 129, 183; 123(6) 173 (rate of increase as measured by slope of best straight line 0.71, *t* 2.617, better than P 0.05). Snout 158, 114; 131, 123 (in head L 2.65, H 3.32, but LL, HH marginally inconsistent). Interorbital 85.0, 91.5; 76.9, 78.5 (in head 4.98, 4.14; 5.37, 5.18). Ocular capsule in head 6.5, 6.1; 6.5, 6.3. Eyeball in head 12.3, 11.7; 12.9, 12.2. Depth, as represented by sum of depths at front of eye, back of eye, operculum, vent 1454, 1238; 1427, 1376 (rate of decrease as measured by slope of best straight line -1.63; *t*, at 2.021, not greatly below P 0.05 value of 2.160). Maximum depth 423, 362; 404, 401 (slope -0.48; 1.782, just better than that for P 0.10). Width, as represented by sum of widths at same points as for depth 696, 573; 657(6), 601 (slope -1.12, *t* 3.457, better than P 0.01).

Thus there are indications that with increasing size of fish direct dimensions that decrease include head, snout, summed depths at several points, maximum depth, summed width at several points; with increases found in interorbital, trunk. The three ratios examined, ocular capsule in head, eyeball in head, interorbital in head, all show decreases in magnitude.

Lengths to Opercular Border, Vent, Hypural Joint

It has been found in these contributions for a number of species that in a loglog plot the lengths of three primary regions of head, head plus trunk,

TABLE 3

Gnathanacanthus goetzeei Bleeker, 1855

Relative growth: decrease in length of fin spines and rays (recorded as millesimals of standard length) with increase in length of fish. Data from 15 Tasmanian examples (figure in round brackets notes number of specimens involved if fewer than full complement). For nature and specification of subsamples see text.

Variate	Correlation		Regression			Subsample means			
	r	*z*	*t*	Slope	Intercept	L (a), (b)	H (n), (o)	LL (a)-(g)	HH (h)-(o)
A	-0.6678	-0.895	3.095	-1.770	1053.3	613	527	773	652
B	-0.6722	-0.875	3.011	-2.113	993.8	665	467	668(7)	507
C	-0.7640	-1.006	3.926	-1.978	729.0	517(1)	321	462(5)	381
D	-0.8640	-1.154	3.433	-5.4551	3104	2380(1)	1754(1)	2204(3)	1870(3)
E	-0.6655	-0.803	2.957	-0.8904	490.9	661	644	707	668(6)
F	-0.7355	-0.996	3.460	-1.0736	530	756(1)	644	730(6)	668(6)
G	-0.6973	-0.862	3.370	-1.6586	1160	860	730	880(6)	802

Variate A: Dorsal spines {1-3}
B: Dorsal spines {last four} (14)
C: Anal spines {1-4} (13)
D: Anal rays {1-8} (6, omitting (b))
E: Anal ray, longest (13)
F: Anal ray, longest (12, omitting (b))
G: Pectoral rays {first,last,longest} (14)

head plus trunk plus tail are linear on three integers of which the first is 1, second 2, the third a number not exceeding 10, most commonly 3. Here the integer set is {1, 2, 10}. In the present sample no such relation could be looked for as holding for each individual fish, inasmuch as relative head length decreases, while relative trunk length increases. However, plotting the mean values is found to yield a statistically significant straight line (t 16.222), with equation log L = 0.3855 log N + 2.6186, where L = {length of head, length to vent, standard length} and N = {1, 2, 10}, successive members of the length set being associated with successive members of the numeral set. The percentage variation of the estimated lengths from the given lengths 406.5, 560.3, 1 000 is 1.0-3.1(2.4), $\bar{x}$ 1.81.

Depth, Width

General

The maximum depth ranges from 340 to 450 *TLs*, with a mean of 404.0 ± 7.76, representing 2.9-2.2, mean 2.48 in the standard length (Waite, 2.6; Ogilby 3 1/3 to 3 2/3 in total length). The range and the mean are very similar to those for the length of the head, namely 359-460, 405.6 ± 6.80 (Bleeker, "altitudine capitis 1 1/3; circiter in ejus longitudine"; Ogilby, "depth of head below the first dorsal spine 1 1/5 to 1 ¼" in head length; Waite depth of body 2.6 in fish length). The mean depth is rather less than the mean pectoral length (last-named notably short in Bleeker's illustration). Largely as the result of genuine individual variation, but perhaps somewhat influenced by the history of preservation, its location may be at the opercular border (5 specimens), at the vent (4), or somewhat in advance of the level of opercular border; however, differences of magnitude among the three locations are in general small. The depth of the caudal peduncle, like its length, is moderate, the minimum depth showing a range of 79-104, $\bar{x}$ 88.9 ± 1.64. The marked increase in depth at base of caudal rays has already been noted. While measurements of depth recorded in diagnoses and descriptions are customarily confined to overall maximum and minimum and of caudal peduncle, useful supplementary information is provided by measurements made at slected morphological loci. In these contributions data are usually provided for the depth at the level of front of eye, back of eye, opercular margin and vent; this procedure is observed here. Depth at front of eye ranges from about one-fifth to somewhat more than one-third of the standard length, with range 219-360 *TLs*, $\bar{x}$ 293.5 ± 9.00. In our

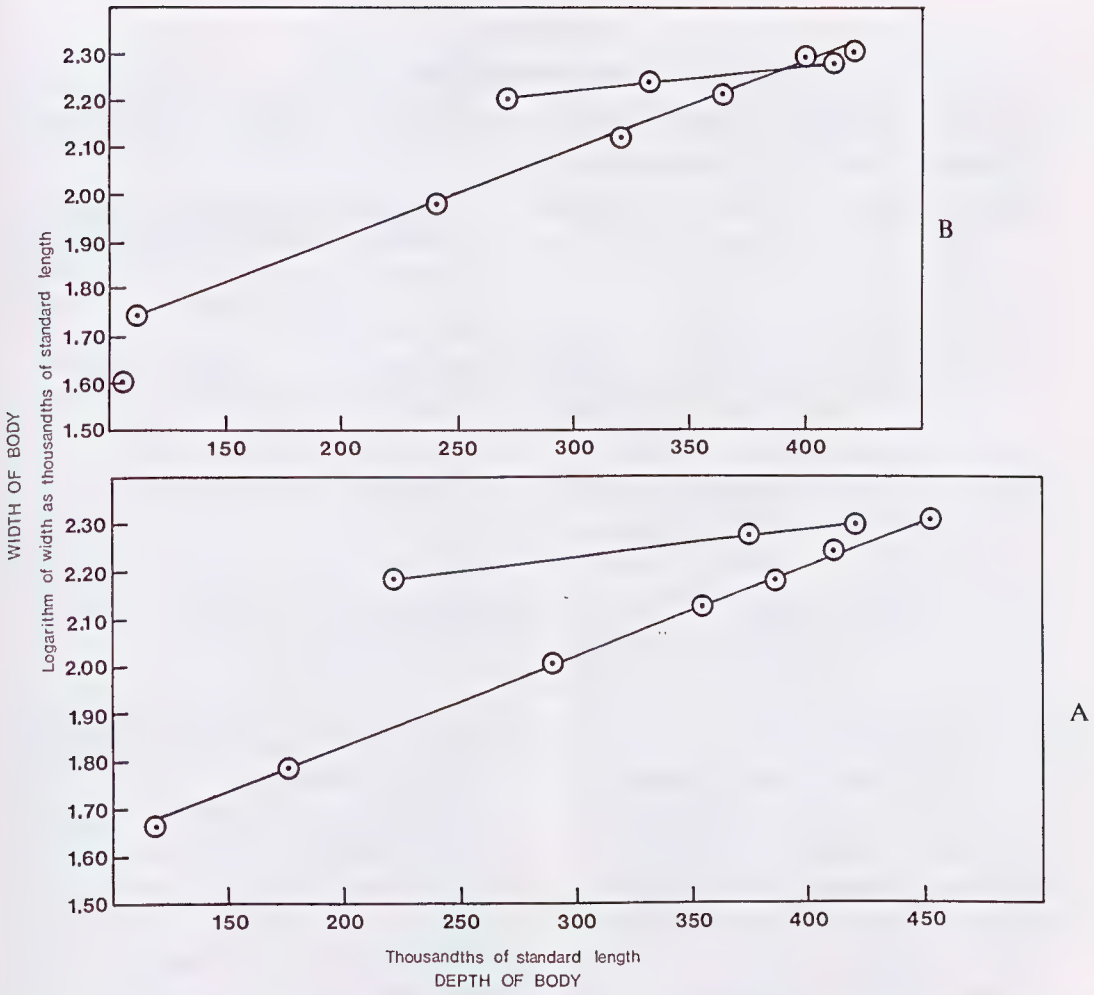

FIG.3 — Gnathanacanthus goetzeei *Bleeker, 1855. Depth-width relationship: ten measurements of width taken at equal intervals between most advanced point and level of hypural joint plotted against ten measurements of depth at the same points. A, specimen 201 mm in standard length; B, specimen 256 mm in standard length.*

material it exhibits a distinctly higher coefficient of variation, namely 11.9, compared with 7.7, 7.3, 6.9, 7.4, 7.2 for depths at the other points of measurement proceeding caudad. In proceeding backward through the short distance to the hind border of the eye the mean height increases to 1.2 that of the front of the eye; 311-401, $\bar{x}$ 346.6 ± 6.88. At the opercular border it has increased to 1.4 the first measurement; 336-433, $\bar{x}$ 396.6 ± 7.43, range and mean here differing only slightly from those at vent, 336-419, $\bar{x}$ 382.2 ± 6.84. Variation of relative depth with size of fish has been noted above in the section on relative growth. Both head and body are notably compressed, a feature noted in all reports. As is commonly the case the compression is associated with a general approximation to flatness; the impression of rotundity given by shading in Castelnau's plate having been criticized by Waite. The width at the front of the eye (121-168, $\bar{x}$ 147.1 ± 3.63) increases slightly at the back of the eye (143-194, $\bar{x}$ 151.8 ± 9.49) and more markedly at the level of the opercular margin (143-216, $\bar{x}$ 182.1 ± 6.03), the last specification being the equivalent of an in-length specification of 7.0-4.6, mean 5.49, and an in-head specification of 2.1-2.5, mean 2.23 (Ogilby 2 2/3 to 2 3/4). Behind this point it exhibits a

TABLE 4

Gnathanacanthus goetzeei Bleeker, 1855

Depth and width measured at ten equidistant points along anteroposterior axis of fish of three specimens, (i), (n), (o), of standard length 201, 235, 256 mm; dimensions as millesimals of standard length. For each of the two decile sets $D = k \log W$ (for parameters see text).

Specimen	Decile set	Depth			Width			Estimated width			Percentage deviation of estimated from measured width	
											Range	Mean
(i)	{1-3}	221	374	420	154	190	200	154	189	201	0.1-0.5 (0.4)	0.32
	{4-10}	451	410	385	205	174	154	207	173	155	0.4-3.0 (2.4)	1.45
		354	285	174	133	103	62	135	99	61		
		118			48			47				
(n)	{1-3}	247	323	366	149	162	170	149	162	170	0.1-0.2 (0.2)	0.16
	{4-10}	374	332	311	128	106	98	126	107	98	0.1-1.9 (1.7)	0.91
		277	157	85	85	55	43	87	55	42		
		115			47			47				
(o)	{1-3}	272	332	412	160	176	192	161	175	193	0.4-0.8 (0.4)	0.53
	{4-9}	420	400	364	200	180	164	200	184	159	0.1-3.0 (2.5)	1.53
		320	240	112	132	96	56	130	95	56		

progressive decrease, to become at the vent only four-fifths value at the front of the eye (102-159, $\bar{x}$ 118.4 ± 10.87). At the four points mentioned the depth relative to the width increases from first (1.99) to second (2.28), decreases to third (2.18) and increases to fourth (3.23). The relation of depth and width considered throughout the length of the first exhibits a precise and interesting pattern discussed in the immdiately following section.

Depth-Width Relationship

When 10 measurements of depth and 10 of width were taken at equal intervals between most advanced point of snout and level of hypural joint in specimen (i), *Ls* 201 mm, the and widths were plotted against the corresponding depths (both as millesimals of standard length; the width logarithmic) there resulted the graph shown in fig. 3a. To permit the comparison with graphs for other specimens measurements made in millimetres have in all cases been rendered as millesimals of standard length. It will be seen that there the graph comprises two lines, the upper connecting deciles 1, 2, 3 (from the left to right), the lower connecting deciles 4-10 (from right to left). Extrapolation of the upper line beyond decile 3 comes close to junction with the lower line at 4; indeed, when the rectification noted below is made the line for deciles {1–4} shows statistical significance at t 21.102. While not invariably demonstrable at formally significant levels, conjunction of the two lines would appear clearly to be the norm.

In specimen (i) the equation for the decile set {1-3} is $\log W = 0.0005739\ D + 2.0613$; with r 0.9987 (z 3.670), significant at t 19.610. For the set {10-4} the parameters are 0.001929, 1.4470; with r 0.9994 (z 4.077), t 65.914. If the extrapolation beyond 3 to 4 is made, thus linking the two segments, the parameters for {1-4} become 0.0005530, 2.0668; r 0.9978 (z 3.400), t 21.102.

Apart from an anomaly at times involving deciles 9 and 10, apparently occasioned by the fact that a small pad-like structure, resulting in a brief local increase in width, that may be or (a post-mortem condition?) may not be developed on either side in the region of locally extnded depth at the hypural, a similar two-line graph is yielded by other specimens. For specimens (n) and (o), *Ls* 235, 256, the slopes and intercepts for the deciles {1-3} are 0.0004842, 0.0005635 and 2.0551, 2.0527; for the lower line [deciles {9-4} only in (o)] 0.001638, 0.001789 and 1.4844, 1.5509. For (n) the correlation coefficients are r 0.9995 (z 4.195), 0.9996 (z 4.278); for (o) 0.9971 (z 3.274) 0.9993 (z 3.966): t values are 33.168, 80.609; 19.610, 65.914. In specimen (n), *Ls* 235, plotting of width and depths as millesimals arithmetically yields two upwardly concave arcs as also in (i), in the largest of the three examples

examined, (o), *Ls* 256, the upper arc is upwardly convex — a condition encountered in *Pseudaphritis bursinus* (Cuvier, 1830) and previously illustrated (Scott 1982, fig. 8a). The graph for width and depth of specimen (o) is presented here as figure 3b.

Decile measurements of depth and width for these three individuals are recorded, in two sets for each, in table 4, together with estimates of width as given by the relevant regression equations. To obviate the recording of two (closely similar) values for decile 4 that would result from calculations for both the sets {1-3} and {1-4} only those yielded by the former are noted.

This precise and interesting relation subsisting between width and depth is not here recognized for the first time, a two-arc sublenticular curve having previously been reported (1982: 210, figs 8, 9) for the bovichthyid *Pseudaphritis bursinus* (Cuvier, 1830) and having earlier been encountered in an unpublished study of a scombrid, *Thunnus maccoyii* Castelnau, 1872. As is the case here, the decile sets involved are {1-3}, {10-4}, the arithmetic curve for the former, however, there being upwardly convex instead of upwardly concave. It would seem probable this arithlog formulation of depth-width represents the specification of some profound morphological significance (presumably with hydrodynamic implications) in these fish; and might well be found to be applicable, with appropriate parametric adjustments, conceivably associated with the existence of decile sets other than the present two, to other species as yet unexamined.

General Form

In the subjoined account recorded dimensions are in general derived from all 15 specimens listed above; in instances in which such is not the case the number of examples involved is noted in round brackets. Except where otherwise indicated linear dimensions are given as thousandths of standard length, *TLs*.

Lateral Aspect

While the depth is less at the posterior end than at the anterior, the general outline is far removed from the conventional backwardly tapering fish form, being perhaps most appropriately characterized as comprising a subquadrangular trunk, flanked by a subtriangular head and (discounting the caudal peduncle) a subtriangular tail of more or less equal dimensions. The approximation of the dorsal and ventral profiles between the dorsal and anal fins is such that in 11 individuals the depth at the end of the head never exceeds 1.1 that at the end of the trunk, while in one example these dimensions are equal and in three the posterior depth is greater than (1.1, 1.1, 1.01) the anterior. The resultant "chunkiness" that characterizes the fish is better depicted in Bleeker's plate and in Mrs Meredith's painting (Lord & Scott 1924) than in the illustration by Waite, in which the backwardly downward slope between level of eye and level of beginning of soft-rayed dorsal is noticeably overemphasized, and in that by Castelnau, which shows an exaggerated elevation of a short section of the profile above the eye, a region actually barely above, or even slightly below, the profile further back close to the level of pectoral insertion. In Mrs Meredith's painting and in the photograph by Edgar *et al.*, the body margins are largely obscured by the outspread fins.

Between the upper lip and the first dorsal spine the profile is subject to considerable individual variation, ranging between a complex sequence comprising an inferior short concave segment, a longer pronouncedly convex one ending near the level of the upper rim of the orbit, a longer less deep concavity and a short terminal convexity before the base of the spine (pattern essentially as in Bleeker's figure), and a simple virtually even concave sweep (seldom, however, as deep as in Waite's figure); some individuals present a continuous line close to linear. The modal overall angle of the forehead ranges from 55°, through a modal value of about 50° to a minimum of close to 40°, this last value characterizing the figures of Bleeker, Castelnau and Waite. Caudad of this the profile extends, as already noted, more or less straight to, or past, the origin of th second dorsal, thereafter continuing rather strongly convexly down to the termination of the fin, about on a horizontal level with the middle of the eye (too low in Waite). The superior border of the caudal peduncle is distinctly concave, ascending noticeably towards the insertion of the uppermost caudal ray.

The inferior profile back to the origin of the ventral fin descends about two-thirds as much as the dorsal profile ascends through the same horizontal distance, being distinguishable, though not trenchantly, into two arcs, the shorter anterior ending near the level of the end of the isthmus, or, by virtue of the downward expansion of the lowest branchiostegal ray, somewhat behind this. The belly is virtually straight (see Bleeker; Waite's figure suggests a concave margin). From the vent, or from the adjacent first anal spine, an even convex sweep extends to anal termination, its level here horizontal with the angle of the gape. The inferior margin of the caudal peduncle is symmetrical with the superior margin, with again a noticeable

curve to meet the relevant caudal ray. The depth at the level of the hypural joint is 1.1-1.5, $\bar{x}$ 1.30 ± 0.032 times (14 specimens) the minimum depth of the peduncle at its middle.

Ventral Aspect

The nature of the ventral surface in the region of the isthmus, characterized by the occurrence in Gnathanacanthidae of an intermandibulary pad not found in other families of the suborder has already been described and is illustrated in figure 2. From behind the rounded snout and the moderately outwardly sloping outline of the remainder of the head, the ventral surface back to the level of the vent comes close to being rectangular, about twice as long as wide. From the vent caudad the outline tapers strongly, decreasing at the caudal peduncle to about half its initial width, the borders being virtually linear. The head and trunk, particularly the latter, are notably flattened beneath, while in the tail the lateral surfaces descend to become more or less rounded off adjacent to the anal base and on the caudal peduncle. The vent commonly takes the form of a moderate-sized opening, typically circular but at times showing some tendency towards ellipticity, the long axis anteroposterior; provided with a sphincter, its presence indicated externally by a fairly conspicuous ridge. It is located (14 specimens) at 497-606 *TLs* units, $\bar{x}$ 560.4 ± 7.974 behind tip of snout, the interval between it and the insertion of the first anal spine being somewhat variable.

Aspect

Viewed strictly from in front, the fish, apart from the fins, is visible back to, or somewhat beyond, the end of the operculum, behind which it narrows to visual extinction. The interorbital region, with some upward extension to the origin of the first dorsal and a downward continuation to just below the upper nostril presents an almost flat platform considerably in advance of the rest of the head nearby, its sides for the most part linear or slightly concave, about the same distance apart throughout most of their extent, but widening slightly to embrace the anterior nostril.

Overall Body Form

In terms of the systematic description of body form proposed by Gregory (1928) this species is specified thus: (1) hypsisomatic (strongly), (2) gasterion postapical (exceptionally preapical), (3) apex anterior (exceptionally median), (4) gasterion median, (5) hypsinotic (strongly), (6) bathygastric (strongly), (7) leptopygidial, (8) opisthion preuranic (noticeably). This combination of variable body factors is not exhibited by Tasmanian representatives of the five families of the suborder Scorpaenidei reported from our waters, points of difference including: Scorpaenidae nomopygidial; Triglidae, Aploactinidae and Synancejidae mesonotic, mesogastric; Pataecidae (*s.s.*) dolichogastric.

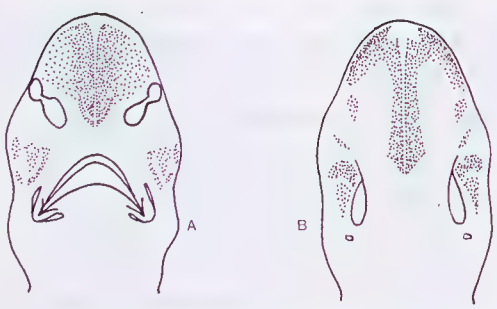

FIG.4 — Gnathanacanthus goetzeei *Bleeker, 1855. A, lower surfaces of head; B, upper surface, showing disposition of ampullae of Lorenzini.*

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(accepted Sept. 19, 1985)

POTASSIUM-ARGON AGES OF TERTIARY VOLCANICS ROCKS, TASMANIA

by F.L. Sutherland and P. Wellman

(with one table and four text-figures)

SUTHERLAND, F.L. & WELLMAN, P., 1986 (12:ix): Potassium-argon ages of Tertiary volcanic rocks of Tasmania. *Pap. Proc. R. Soc. Tasm.*, 120: 77–86. ISSN 0080-4703. Australian Museum, 6-8 College St, Sydney, N.S.W. 2000 and Bureau of Mineral Resources, Geology and Geophysics, P.O. Box 378, Canberra City, A.C.T. 2601.

Sixteen new K-Ar dates are presented from Tasmanian and Bass Basin basalts, more than doubling the previously published number. Eight volcanic regions are described, based on boundaries established on the range of the basalt types contained in each geographic region. Volcanism occurred within the span from Eocene to Miocene (47 to 13+ Ma), but mainly within the time range Middle Eocene to Early Miocene. Alkali basalts erupted throughout this span and are interspersed with tholeiites (22-31 Ma), fractionated alkaline rocks (22-27 Ma) and rare melilite-bearing varieties (26-35 Ma).

Key Words: basalt, Tasmania, K-Ar ages.

INTRODUCTION

The Cainozoic igneous rocks of Tasmania are all mafic, but they have a wide range in composition — from tholeiitic to alkaline and including some fractionated types with Ab/Ab+An > 0.55 (Edwards 1950; Spry 1962; Sutherland 1969a, 1974; Frey *et al.* 1978). In most areas the flows include a variety of basalt types and their field relationships often suggest separate volcanic episodes with intervening sedimentation and/or erosion (sections, figs 2-3). Previous K-Ar dating consists of 12 dates from five areas (Sutherland *et al.* 1975; Green 1976; Sutherland 1976, 1977a; Brown 1977; Cromer 1980). Although 16 new dates (table 1) are presented, more KAr dating is required to define adequately the age of Cainozoic volcanism. The basaltic rocks are assigned here to eight volcanic regions (fig. 1 and table 1) each with geographic boundaries enclosing a different range of basalt types. These volcanic regions fall within the time spans and chemical variations found in petrographic provinces (Rock 1981), but are not clear cut provinces with discrete and distinct chemical character.

Where older dates in the literature are quoted, they have been recalculated using modern values of constants (after Dalrymple 1979), i.e. $^{40}K/K = 1.167 \times 10^{-10}$ moles/mol, $\lambda\beta = 4.962 \times 10^{-10}$ yr^{-1}, $\lambda\epsilon = 0.05811 \times 10^{-10}$ yr^{-1}. Freshness of samples with respect to loss of radiogenic argon is estimated as A (completely fresh phases), A-B (fresh K-bearing phases, but with slight alteration of other phases or presence of minor glass), B (some alteration of K-bearing phases) or C (significant alteration of K-bearing phases). The relevant boundaries of the time scale used here (Hardenbol & Berggren 1978), involving the new decay constants are: Quaternary — 1.8 Ma; Pliocene — 5.5 Ma; Miocene — 24.6 Ma; Oligocene — 38.0 Ma; Eocene — 54.9 Ma; Palaeocene — 66.6 Ma.

REGIONS AND AGES

Northeastern Tasmania (Figs 1 and 2)

This region contains undersaturated basalts which both cap hills and crop out in the valleys (Brown *et al.* 1977).

Weldborough area Three basalts give dates of 46.2 ± 0.6, 47.4 ± 0.5 and 47.2 ± 0.6 Ma (Early Eocene, table 1). Although the rocks are slightly altered (A-B), the age of the volcanism is thought to be 47 Ma, because the K-Ar dates agree to within experimental error, and alluvial zircons associated with the basalt give fission track dates that agree with the K-Ar age to within experimental error (Yim *et al.* 1985). This is the oldest Tertiary volcanism identified in Tasmania and the volcanic structure shows considerable erosion (Section A-B, fig. 2).

Analyses of the basalts show that they range from mildly undersaturated to transitional alkaline basalts of sodic affinities (Brown, in McClenaghan *et al.* 1982). Between Blue Tier and Weldborough Pass the base of the volcanics ranges from 500 to

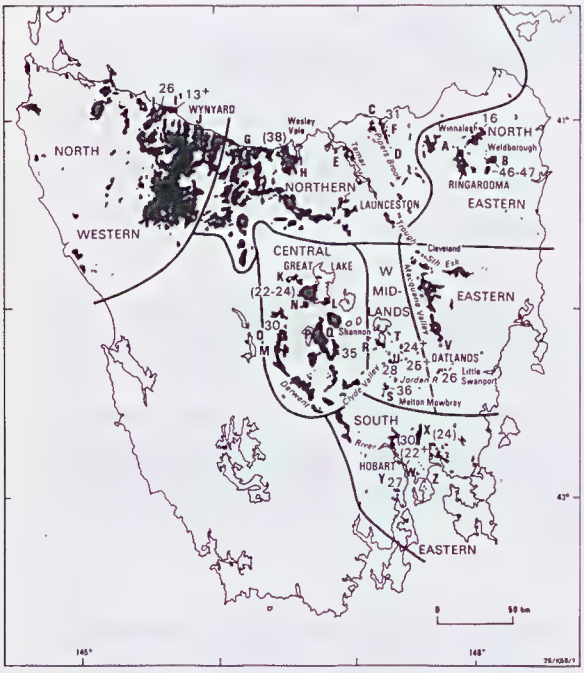

FIG. 1 — Tasmania showing distribution of basalts (black), Tasmanian volcanic regions (boundary lines), K-Ar dates from both this (unbracketed) and previous (bracketed) reports and section lines.

800 m; 150 mof agglomerate and tuffs stratigraphically underlie 230 m of flows. Eruptive centres are thought to be at Weldborough Pass, 2 km SW of Forest Lodge and possibly under Mt Littlechild. Basalts with similar petrology form outlying dykes and cap Grays Hill 16 km to the west above 420-500 m altitude. Winnaleah-Ringarooma area.

The basalts here form partly dissected flows giving Middle Miocene ages of 16.0, 16.3 and 16.4 ± 0.3 Ma (Brown 1977; McClenaghan *et al.* 1982). Analysed flows range from olivine nephelinite to glomeroporphyritic alkali basalt. Flows extend 40 km along the Ringarooma Valley, with a base from 300 m (in the south) to 160 m (in the north) in altitude; they are 20 to 70 m above the Ringarooma River bed. In places they overlie Early Miocene sediments (Brown 1978).

The younger ages of these basalts compared to the Weldborough hill caps confirm the physiographic interpretations of two ages by Nye (1924), Nye & Blake (1938) and Edwards (1939), but the actual ages are greater than their estimates.

Northern Tasmania (Figs 1 and 2)

Basaltic flows lie mainly within valleys draining northward into Bass Strait (Sections C-D, E-F, G-H, fig. 2). They commonly overlie or are interbedded with Cainozoic sediments (Spry 1958; Jennings 1963; Burns 1964; Marshall 1969; Jennings & Sutherland 1969; Sutherland 1971a) and in places the basalts flowed into dammed river systems (Sutherland 1980). The flows are olivine nephelinites ranging through alkali basalts to quartz tholeiite.

In the eastern part, at Pipers Brook the basalts extend from 600 m to below sea-level over a distance of 20 km. Alkali olivine basalt is overlain by tholeiitic flows, and capped by Cainozoic sediments, alkaline basalt and olivine nephelinite. A reasonably fresh quartz tholeiite (A-B) from the lower sequence gave a date of 30.7 ± 0.4 Ma (Middle Oligocene, table 1). The interbedded nonmarine sediments here at Pipers Brook and elsewhere in the region (Burns 1964; Sutherland 1973a) are thought to be related to nearby high sea-levels in the mid-Tertiary. Some flows overlying these sediments are extensively dissected and weathered, so they may be older than the less dissected Middle Miocene flows of the Winnaleah region.

The Early Oligocene basalt fill in Pipers Brook supports the contention that many of the valleys draining into Bass Basin were already blocked by lavas, which impeded ingress of mid-Tertiary high seas (Sutherland 1973a). These blocked valleys only allowed minor Miocene marine incursions on to the coast, judging by the limited outcrops of marine sediments (Quilty 1972). The evidence suggests that volcanism within the drainage system into Bass Strait mostly occurred from Middle Eocene to at least Early Miocene time.

In the western part, a lower porphyritic olivine basalt flow in the Wesley Vale sequence gave a 38.1 ± 0.6 Ma date (latest Eocene, Cromer 1980). Nearby basalts at East Devonport may be of similar age because they are interbedded with palaeontologically dated Late Eocene-Early Oligocene sediments (Sutherland 1973a).

Slightly older alkali basalts may be present in the Longford Basin where they are interbedded with sediments which contain Middle to Late Eocene palynological assemblages, but sampled basalts proved unsuitable for K-Ar dating (Matthews 1983).

Northwestern Tasmania (Figs 1 and 2)

The largest volume of Cainozoic lava is in northwestern Tasmania. The flows range from

TABLE 1

K-Ar Ages for Samples from Tasmanian Regions

Sample No. and Location	Latitude S	Longitude E	Alt.	K %	$^{40}Ar^{*}$ ($\times 10^{-10}$ moles/g)	$^{40}Ar^{*}/^{40}Ar$ total	Age ± I.S.D. (Ma)
Northeast Tasmania:							
BT2, 5.5km SSE of Weldborough	41° 14.4′	147° 55.3	A-B	0.732,0.735	0.59511	0.879	46.2±0.6
BT4, 7.5km S of Weldborough	41° 16.0′	147° 55.2′	A-B	0.691,0.691	0.57408	0.788	47.3±0.5
BT5, 6.6km SE of Weldborough	41° 14.7′	147° 57.1′	A-B	0.771	0.64299	0.870	47.4+0.6
				0.772	0.63815	0.862	47.0±0.6
Northern Tasmania:							
PB1, 2.2km NW of Pipers Brook	41° 04.2′	147° 09.7′	A-B	0.291,0.292	0.15680	0.709	30.7±0.4
Northwestern Tasmania:							
TC1, Tollemore quarry, Table Cape	40° 57.1′	145° 42.3′	B	1.276,1.281	0.29616	0.815	13.3±0.2
SC1, Shekleton Creek, Boat Harbour	41° 00′	145° 36′	A-B	1.125,1.124	0.5169	0.927	26.3±0.3
Central Tasmania:							
ST1, Haystack, Shannon Tier	42° 11.1′	146° 56.9′	A-B	1.589,1.587	0.98416	0.946	35.4±0.4
LJ1, Laughing Jack Marsh, 10.3km WSW of Bronte	42° 09.5′	146° 22.3′	A	1.123,1.119	0.59110	0.910	30.1±0.4
Southeastern Tasmania:							
SB1, Sandy Bay 4km SE of Hobart GPO	42° 55.9′	147° 21.4′	A-B	2.680,2.680	1.24160	0.968	26.5±0.3
CR1, Coal River, 3km NW of Campania	42° 39.0′	147° 27.2′	?	1.76	0.1379*	0.673	24.2±1.0
Western Midlands and Eastern Tasmania:							
BW1, Big White Hill, 4.7km NNE Melton Mowbray	42° 25.9′	147° 11.9′	A-B	1.288,1.286	0.81971	0.570	36.3±0.5
RH1, Rose Hill Farm, 4km WNW of Jericho	42° 22.4′	147° 14.2′	A	1.214,1.213	0.58493	0.901	27.6±0.4
BH1, Barwicks Hill, 3.5km WNW of Oatlands	42° 16.9′	147° 20.3′	B	2.060,2.050	0.89760	0.905	25.0±0.3
FH1, Fernleigh Hill, 4km WNW of Oatlands	42° 16.9′	147° 19.6′	B	1.740,1.740	0.73818	0.945	24.3±0.3
PP1, Pencil Point, 9km ESE of Andover	42° 21.2′	147° 33.3′	A-B	0.497,0.495	0.2220	0.416	25.6±0.2
Bass Basin:							
CN1, Cormorant No.1, Core 11, 8100-8116 ft	39° 34.3′	145° 31.8′	A-B	6.874,6.866	2.690	0.784	22.4±0.1

Alt. = alteration

* ($\times 10^{-5}$ cc/gm)

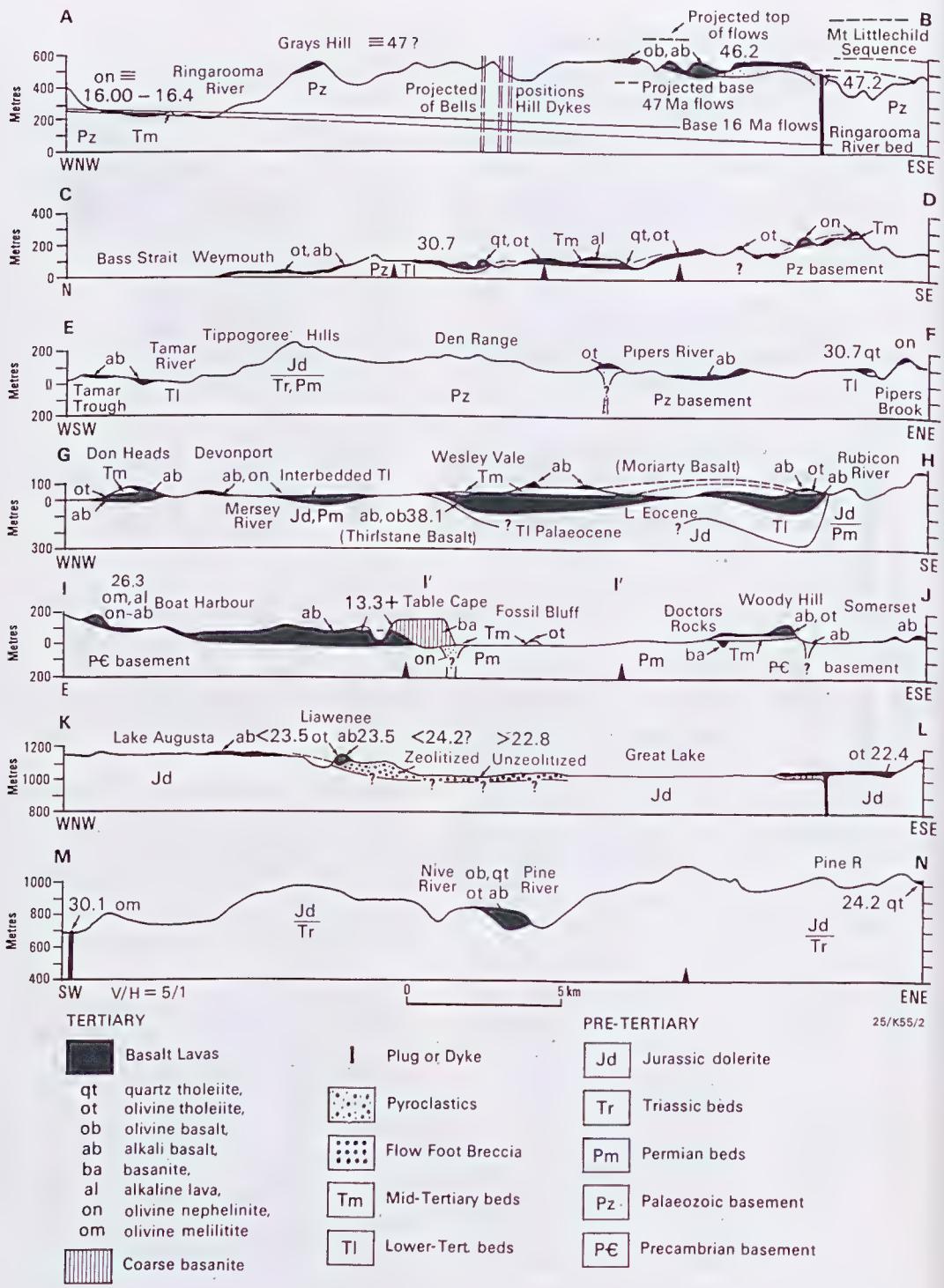

FIG.2 — Sections through dated basalt regions, NE, N, NW and central Tasmania, in relation to physiography, petrology and volcanic sources. Notches on the section base indicate dog-legs in the section line to show basalt sequences to best advantage.

olivine melilite nephelinite to olivine tholeiite. The lavas overtopped the valleys to form an extensive lava plain, including Late Eocene-Early Oligocene sediments (Brown & Forsyth 1984). This plain has an upper surface near 100 m in altitude at Wynyard and rises to the south, reaching 750 m altitude 70 km inland (Burns 1964; Barton *et al.* 1966; Sutherland 1969b; Gee 1971, 1977; Brown & Forsyth 1984). In the far northwestern part of the island lavas are less extensive but are notable for the high proportion of aquagene basalts erupted into mid-Tertiary seas (Sutherland & Corbett 1967; Quilty 1972; Sutherland 1969b, 1973a, 1980).

Between Wynyard and Somerset limburgitic basalts are overlain by latest Oligocene-earliest Miocene marine sediments and minor aquagene breccias of olivine tholeiite (Gee 1971, 1977; Sutherland 1973a). These are overlain by a thick sequence of basalt flows (Section I-J, fig. 2), weathered for the most part. West of Table Cape the basalt succession has been eroded and lateritised. A thick fill (177 m) of coarse unlateritised basanite overlies nephelinitic pyroclastics at Table Cape. A slightly altered sample of this basanite (B) gave a Middle Miocene age of 13.3 ± 0.2 Ma (table 1).

In the sequence between Table Cape and Boat Harbour, an olivine melilite nephelinite flow overlies an anorthoclase-bearing nepheline mugearite in Shekleton Creek, and is the source of the gem zircon and corundum of the district (Gee 1971; Matthews 1973; Hollis & Sutherland 1985). Dating of the Shekleton Creek melilite nephelinite gave 26.3 ± 0.3 Ma. Thus, the basalts in the Wynyard region include Late Oligocene or older alkaline rocks (>26.3 Ma), Early Miocene olivine tholeiite and Middle Miocene nephelinite-basanites (>13.3 Ma).

Central Tasmania (Figs 1, 2 and 3)

This region contains lavas that were erupted onto the Central Plateau, and also lavas that descended south from the plateau, into the Derwent drainage west of the Clyde Valley. Lavas range from olivine nephelinite to quartz tholeiite and there are rare plugs of olivine melilitite and melilite nephelinite. The flows extend over 80 km, being extruded both subaerially and into lava-dammed rivers in sequences up to 400 m in thickness (Spry 1962; Sutherland & Hale 1970; Sutherland 1973b, 1980). Sutherland *et al.* (1973) dated five lavas from the predominantly tholeiitic sequence near Great Lake (Sections K-L, M-N, fig. 2). As the ages of the lavas range from 22.4 to 24.2 ± 0.6 Ma, most of the lavas of the region are likely to be Late Oligocene-earliest Miocene in age.

Plugs of olivine (monticellite) nepheline/melilite rocks are known at Shannon Tier on the eastern side of the region (Twelvetrees 1902; Edwards 1950). A sample from one (A-B) gave a 35.4 ± 0.4 Ma age (Early Oligocene, table 1). A plug of olivine nepheline melilitite (A) at Laughing Jack Marsh (Sutherland 1973b; Brey & Green 1975; Frey *et al.* 1978) gave a younger, 30.1 ± Ma age (Middle Oligocene, table 1). Both these highly silica-undersaturated intrusions are therefore older than the dated flows in the region (Sections M-N, O-P, Q-R, figs 2 and 3).

Western Midlands (Figs 1 and 3)

Basalts here range from olivine nephelinite to alkali basalts and include fractionated alkaline lavas. On the southwestern side undersaturated lavas extend from the Central Plateau at around 900 m near Interlaken to 420 m altitude near Oatlands (Forsyth 1976). The basalts at different levels (Sections S-T, U-V, fig. 3) differ petrologically and many are related to local centres (Sutherland 1971b, 1984). Although originally in valleys many now form cappings to hills; individual flows can be traced from hilltop to hilltop for up to 10 km. The flow at Big White Hill north-northeast of Melton Mowbray gave a date of 36.3 ± 0.5 Ma (Early Oligocene, table 1). It is up to 90 m thick and filled a valley. It caps two isolated hills close to the Jordan River — its base is 500 to 380 m altitude and well above the Jordan River at 210 m. The Jericho plug at Rose Hill Farm some 6 km to the north gave a date of 27.6 ± 0.4 Ma (Late Oligocene, table 1). It is at 400 m altitude and is the inferred feeder for a petrologically similar flow filling an ancestral gully of Rose Hill Creek at 420 to 500 m altitude some 2 km to the west. About 13 km to the northeast, near Oatlands township two flows overlie volcanic breccias (Sutherland 1984). The eastern flow (at Barwicks Hill) is a nepheline hawaiite flow, with a base at 420 to 460 m; a sample (B) gave a minimum age of 25.0 ± 0.3 Ma (Late Oligocene, table 1). The western flow (at Fernleigh Hill; Sutherland 1984 and Forsyth 1984, p.154) according to field evidence is a younger hawaiite flow which has a base at 540 to 560 m. Samples are rarely fresh (B) and give a minimum date of 24.3 ± 0.3 Ma (Oligocene-Miocene boundary, table 1). The undersaturated lavas in this region therefore mostly give Middle to Late Oligocene ages, considerably older than suggested by Edwards (1939) on physiographic interpretations.

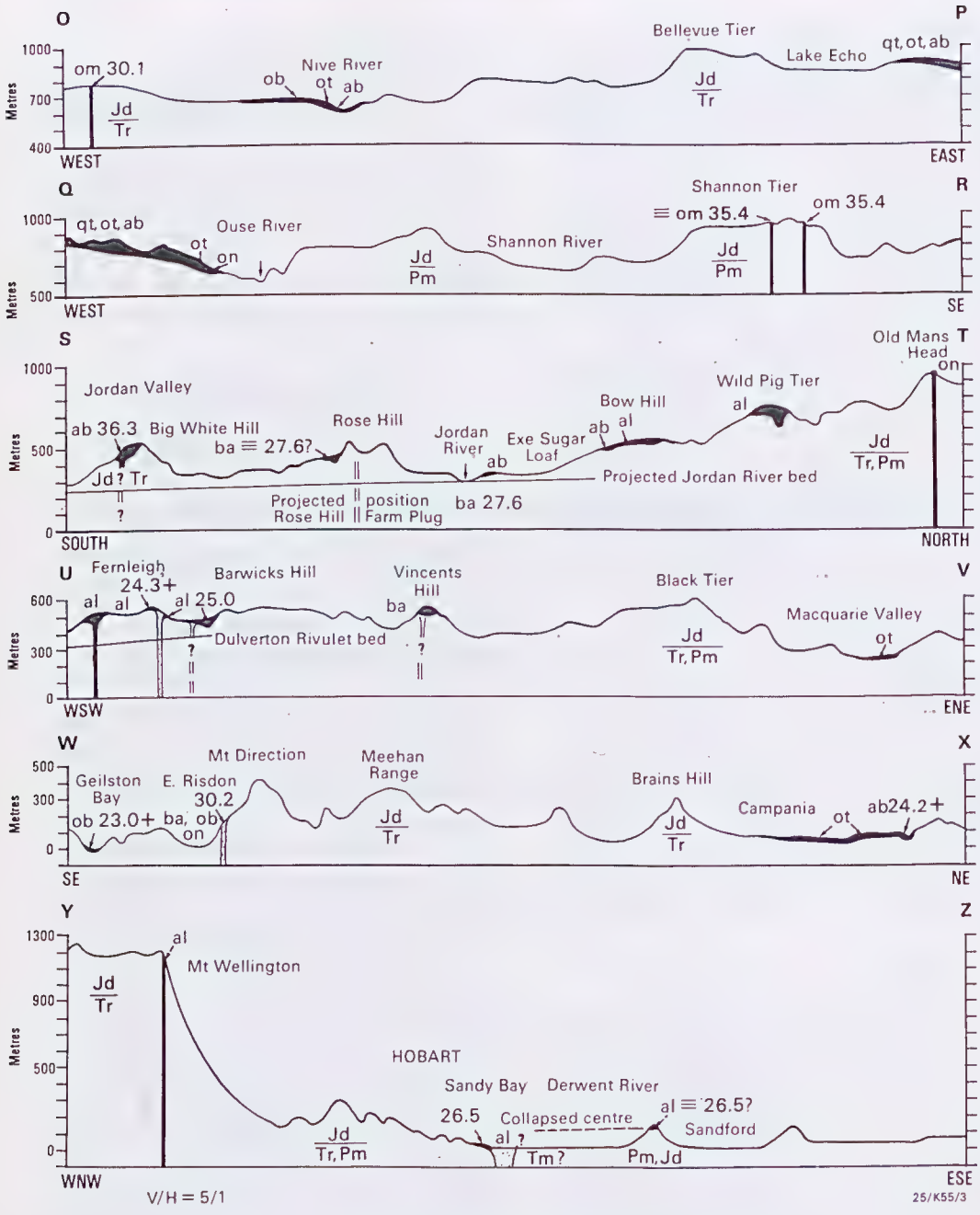

FIG.3 — Section lines through central, western Midlands, eastern and southern Tasmania. Legend as in Fig. 2.

Eastern Tasmania (Figs 1 and 3)

Tholeiitic lavas are more common than undersaturated lavas in this region and flowed for 50 km north down the ancestral Macquarie and South Esk and east down the Little Swanport River valleys. They descend from about 400 m to between 180 and 230 m altitude in the north. Here, near Cleveland, the flows fill valleys cut into sediments dated palynologically as Middle to Late Eocene (W.L. Matthews and S.M. Forsyth, pers. comm.). The lateritised flows form part of the Woodstock Surface of probable Pliocene age (Nicolls 1960; Matthews 1974). Samples collected were not fresh enough for K-Ar dating. Following Nye & Blake (1938) we believe that most of these tholeiitic basalts may be younger than the Oligocene alkaline lavas of the western midlands immediately to the southwest (Section U-V). We infer that they are probably Early to Middle Miocene in age. However, in the south at Pencil Point near Andover, an unusual olivine tholeiite flow erupted from a centre; it carries mantle lherzolite xenoliths (Sutherland 1974). This basalt (A-B) gives a date of 25.6 ± 0.2 Ma (table 1). This indicates some Late Oligocene overlap between the tholeiites and the alkaline eruptions of the western Midlands even though quartz tholeiite overlies nepheline mugearite near Lemont.

Southeastern Tasmania (Figs 1 and 3)

The most widespread flows are olivine tholeiites erupted into the valleys of the lower Derwent and Coal Rivers (McDougall 1959; Sutherland 1976, 1977a, 1980). Some of these lavas eruptedinto or flowed into water. No suitable tholeiitic rocks for K-Ar dating have been found. Tholeiites overlie an alkali basalt near Campania in the Coal Valley (Section W-X, fig. 3); the alkali basalt gives a minimum 24.2 ± 1.0 Ma age (earliest Miocene, table 1; Sutherland *et al.* 1973; Green 1976; Sutherland 1977a) and a sample of considerably altered tholeiite (C) gave an age older than 10 Ma (D.C. Green and F.L. Sutherland, unpublished). The tholeiitic lavas therefore may be latest Oligocene or Early Miocene in age.

Alkali basalts and fractionated alkaline lavas form short valley flows and pyroclastic centres around Hobart from D'Entrecasteaux Channel to Tasman Peninsula (Brill & Hale 1954; Spry 1962; Sutherland 1985). Amphibole from a tuff interbedded in the East Risdon volcanic centre gave a 30.2 ± 1.0 Ma age (Middle Oligocene; Sutherland 1976; Green 1976). A nearby olivine basalt flow

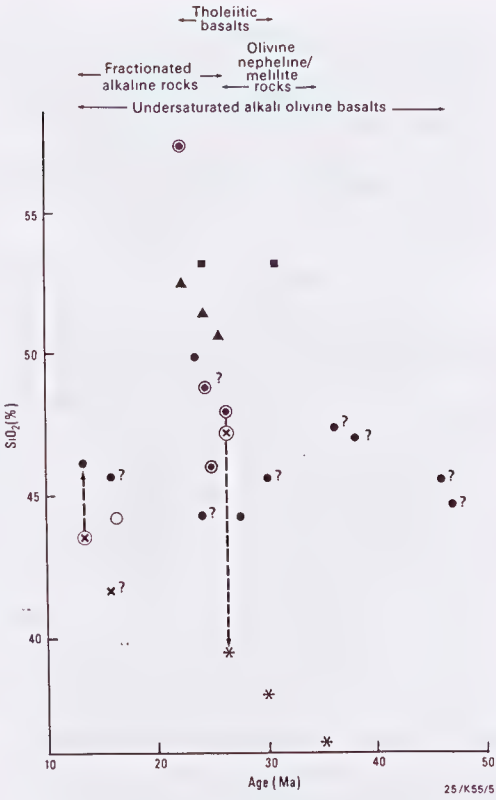

FIG.4 — SiO_2 versus age (Ma) plots for dated Tasmanian basalts, showing petrographic types vis. olivine melilitite/nephelinite rocks (asterisks), olivine nephelinites (crosses), basanites (open circles), olivine tholeiites and transitional basalts (filled triangles) and quartz tholeiites (filled squares). More fractionated alkaline rocks of these lineages (Ab/Ab+Ab > 0.55) are indicated by circles enclosing the lineage type. Dated rocks with no available chemical analyses are shown at approximate SiO_2 content, based on analogy with petrographically similar analysed rocks taken from the cited literature, and are indicated by question marks. Age spreads of highly undersaturated melilite-bearing rocks, undersaturated alkali basalts, tholeiitic basalts and more fractionated alkaline rocks are shown by tied arrows. Rocks immediately underlying and closely connected with dated basalts are linked by dashed arrows.

overlying a fossil marsupial site gave a minimum age of 23.0 ± 0.5 Ma (Tedford *et al.* 1975). The well-studied Sandy Bay volcanic centre (Charles Darwin, reported in Banks 1971; Johnston 1888;

Spry 1955) overlies Cainozoic sediments, with a palynological age of younger than Eocene and probably Yallournian (Oligocene; Gill 1962). The top flow of mafic nepheline benmorite (Sutherland 1974, 1976) has fresh rock (A-B) yielding a date of 26.5 ± 0.3 Ma (Late Oligocene, table 1). The dated alkaline volcanics in southeastern Tasmania (Sections W-X, Y-Z, fig. 3) are therefore Mid-Oligocene to Early Miocene in age.

Bass Basin

In Bass Basin, a similar volume of basalts to that occurring above sea level in Tasmania is interbedded with the sediments (Robinson 1974; Brown 1976). Palaeontological dating suggests that this volcanism ranges from Eocene to Miocene. This is a similar time span to that shown by dated on-shore Tasmanian basalts. The oldest dated Tasmanian basalt (47 Ma, NE Tasmania) is significantly younger than the graben formation and Late Cretaceous-Early Palaeocene sedimentation that extends from Bass Basin into the Tasmanian mainland (Moore *et al.* 1984).

The volcanic successions intersected in Bass Basin bore holes are generally too altered for satisfactory dating, but an intrusion in Early Eocene sediments in Cormorant No.1 bore (B.R. Brown 1976, fig. 5) seemed suitable. The intrusion is an unusual alkaline rock with no known counterpart on-shore in Tasmania; it grades from a picritic cumulate with a hydrous altered groundmass to a coarser analcime-bearing highly sodic and felsic gabbro. It appears to represent a monchiquite intruded into and fractionated within the wet sediments. Biotite separated from the rock is only slightly altered and gives a minimum date of 22.4 ± 0.1 Ma (unpublished data, Bureau of Mineral Resources). The date (table 1) suggests Early Miocene alkaline activity towards the close of Bass Strait volcanism. This activity may include an Early-Middle Miocene monchiquite intrusion at Portland, Victoria (Glenie & Reed 1962), dated as at least 17.5 Ma (Harding 1966).

PETROLOGY AND AGES

The dating and petrological information discussed above is summarised in figure 4. Initial, restricted and mildly alkaline basaltic volcanism in the Early Eocene (Weldborough area; 47 Ma) was followed by more widespread undersaturated volcanism from Middle to Late Eocene to earliest Oligocene (Northern, Central and Midlands regions: 35-38 Ma). Strongly undersaturated to saturated lavas were erupted in the Early-Middle Oligocene (Central, Southeastern, Northwestern and Northern regions: 26-35 Ma). This widespread volcanism continued through the Late Oligocene-Early Miocene but overlapped with some activity leading to fractionated alkaline lavas (Midlands, Eastern, Southeastern, Bass Basin regions: 22-27 Ma). A final phase of undersaturated volcanism is recognised in northern Tasmania around the Middle Miocene (Ringarooma-Winnaleah, Table Cape regions: 13-16 Ma). The total volume of lava erupted in Tasmania was only about 400 km^3 (Sutherland 1969a).

The main 'magmatic message' emerging from the dating of Tasmanian Tertiary volcanic rocks is that oversaturated basalts (approximating to SiO_2 contents above 50% in figure 4) are virtually confined to the Mid-Tertiary episodes (21 to 31 Ma). If these tholeiites represent relatively high degrees of partial melting of mantle source rocks (Frey *et al.* 1978) this correlates with an Oligocene-Early Miocene peak of volcanism. The only other rock with SiO_2 significantly over 50% is the highly fractionated sodic gabbro from Cormorant-1 well in Bass Strait. However, this rock is derived from an undersaturated parent and belongs to the waning stage of volcanic activity in Bass Strait.

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(accepted May 9, 1986)

RECONNAISSANCE GEOLOGICAL OBSERVATIONS ON PRECAMBRIAN AND PALAEOZOIC ROCKS OF THE NEW AND SALISBURY RIVERS, SOUTHERN TASMANIA

by Grant Dixon and Chris Sharples

(with five text-figures)

DIXON, G. and SHARPLES, C., 1986 (12:ix): Reconnaissance geological observations on Precambrian and Palaeozoic rocks of the New and Salisbury Rivers, southern Tasmania. *Pap. Proc. R. Soc. Tasm.* 120: 87–94. ISSN 0080-4703. University of Tasmania, Hobart, Tasmania, Australia, 7000.

Phyllite and quartzite, probably Precambrian, trend meridionally and dip steeply in the New River Gorge above the junction with the Salisbury River in southern Tasmania. Further upstream an association of silty dolomite and conglomerate is less deformed and may be younger. Siliceous conglomerate boulders occur in the New River below the gorge. Late Ordovician carbonates of the Gordon Group are exposed in the New River valley just above the junction with the Salisbury River and up the Salisbury to Vanishing Falls, above which a sheet of Jurassic dolerite seems to have been intruded along the unconformity between the Ordovician rocks and almost horizontal Late Palaeozoic sedimentary rocks of the Parmeener Supergroup.
Key words: Precambrian, Ordovician, Tasmania.

INTRODUCTION

The New and Salisbury Rivers drain a remote area of southern Tasmania. The New River flows southeast from Federation Peak, and passes through a gorge 8 km long before reaching a broad alluvial valley where it is joined by the Salisbury River and flows southwards into New River Lagoon on the south coast of Tasmania. The Salisbury River flows northwards from Precipitous Bluff and over Vanishing Falls before turning westward to flow into the New River (fig. 1). Due to the rugged topography, dense vegetation and absence of tracks, these areas have been rarely visited.

Few geological observations have been made on these rivers. Johnston (1888) reported "Silurian" limestones containing the coral *Strombodes*. An exact location was not given, but Johnston mapped limestone as occurring for about 10 km or so up New River north of the lagoon. Hall (1966) recorded geological observations on the downstream end of the New River gorge which broadly agree with the observations reported in this paper, but differ in some significant details. It is not clear whether the observations recorded in Hall (1966) were made on the ground or by aerial reconnaissance; if the latter was the case it would explain the discrepancies with the present work. A more recent helicopter reconnaissance (Burrett *et al.* 1981 and Burrett pers. comm.) recorded Gordon Group (Burrett *et al.* 1984) limestones on the Salisbury River and a possible outcrop of Denison Group (Burrett *et al.* 1984) conglomerates on the New River just upstream of its confluence with the Salisbury River (the present work suggests that the "outcrop" observed on the New River was actually an allochthonous boulder). Additionally, on the basis of observations and collections made by bushwalkers it has been known for a decade that limestones exist on the Salisbury River at and below Vanishing Falls (Burrett 1978, Farmer 1979).

A topographic depression (referred to here as the "New River Depression") just south of the New River gorge, led to the assumption that carbonate rocks exist in that area.

The present paper records observations made on two occasions. In January/February 1984, Grant Dixon led an Australia and New Zealand Scientific Exploration Society (ANZSES) party down the entire length of the Salisbury River, making the observations reported here; and in January 1985 both authors entered the New River at the upstream end of its gorge and made observations down to New River Lagoon.

All grid references in this paper refer to the Universal Grid Reference System on the Huon 1:100 000 topographic map sheet 8211, (Tasm. Lands Dept 1977). UTGD specimen numbers refer to specimens housed in the Geology Department collection, University of Tasmania.

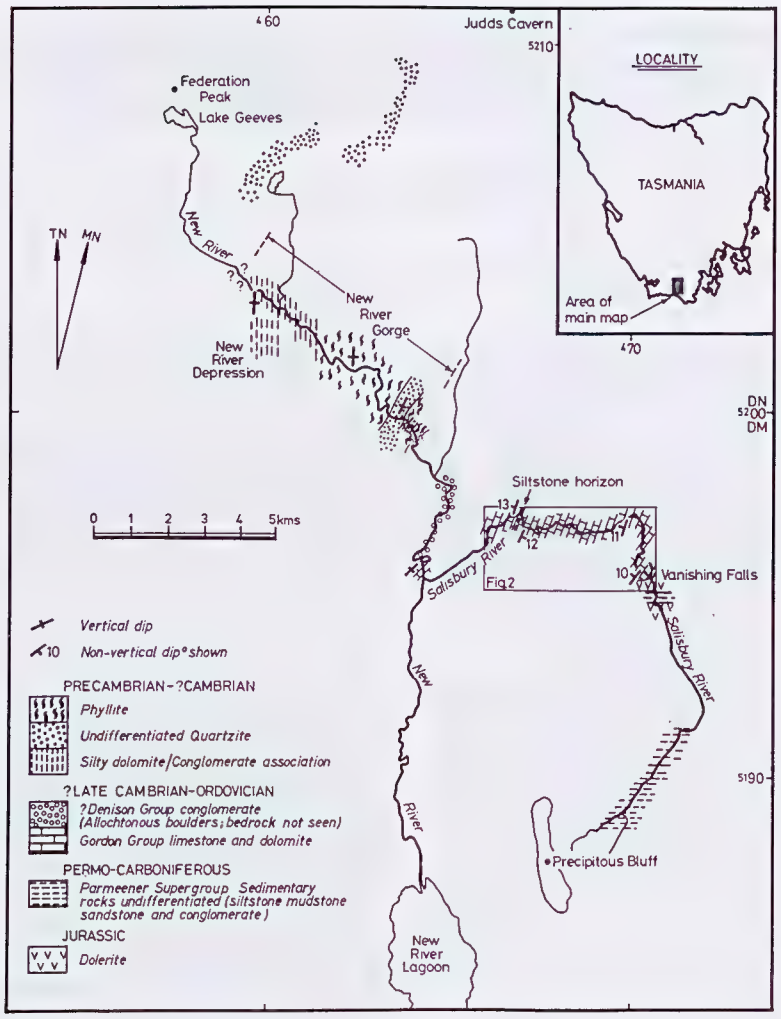

FIG.1 — Geological sketch map of the New and Salisbury Rivers, southern Tasmania, showing only the geological observations described in the accompanying paper.

STRATIGRAPHY

Presumed Precambrian to possible Cambrian

The following three rock types and associations crop out in the New River gorge, and on the high ridge north of the gorge (although the units on the ridge do not necessarily correlate directly with the units in the gorge).

Banded Grey Phyllite

This unit outcrops in the New River gorge. The furthest upstream outcrop observed is at DN614020, and the furthest downstream outcrop is at DM640995. Two major quartzite horizons within the phyllite are described separately below. The phyllite is grey, greenish or rarely pinkish, with light and dark bands 10 mm or so thick throughout. Mica is abundant. At least two generations of complex small-scale folds are ubiquitous. Although major fold closures were not observed, major tilting has occurred along north-south trends. Dips are very steep, varying from about 70° towards the east (e.g. at DN614020) to vertical to about 70° towards the west (e.g. at DM632007). Strikes are approximately meridional. Folded quartz veins are common, and jointing of several trends occurs.

Quartzites

At the eastern end of the high ridge north of the New River gorge, at approximately DN625070, white and pink quartzites occur, which are bedded on a scale of about 0.5 m and have cross-lamination structures. Conglomerate interbeds are present. At the western end of the aforementioned ridge, at approximately DN600067, white quartzites occur with complex small-scale folding.

Two quartzite bands occur close together within the phyllite at the downstream end of the New River gorge. Grey phyllite is observed in outcrop upstream, downstream and in between the two quartzite bands, but the contacts were not observed. The thickest quartzite band forms a high narrow ridge known as "Gibraltar", which the river cuts through at DM634998 to form a deep and dramatic chasm. The quartzite here is hard and white or purplish/red, with abundant white quartz veins. The quartzite dips vertically or very steeply towards the east, with an approximately north-northeast strike. The smaller quartzite band crops out in a short, narrow chasm at DM640996, a few hundred metres downstream from the main quartzite band, and is of similar appearance to the latter.

Silty Dolomite/Conglomerate Association

Interbedded silty dolomite and coarse conglomerate crop out in the upstream part of the New River gorge (fig. 1), from approximately DN596033 or further upstream, to a point upstream of DN614020. The contact with the phyllites which crop out at DN614020 was not observed, the last outcrop in a downstream direction being at DN612023.

The silty dolomite appears as a fine-grained, reddish-brown to dark yellowish-brown sedimentary rock, well-bedded with planar to slightly crinkled bedding planes 1 to 2 mm apart. Some outcrops show crinkled white stringers about 1 mm thick along bedding planes. Quartz veins up to 100 mm thick commonly cut across bedding.

A stained thin section was prepared of a dolomite sample collected at DN600030 (UTGD 68100). The specimen has a dolomite microspar matrix (0.05 mm diameter anhedral grains) containing well-rounded oval intraclasts, averaging 2.0 to 4.0 mm long and 0.5 to 2.0 mm wide, of dolomite and minor ferroan dolomite spar. A strong alignment of the intraclasts gives the rock a distinct planar fabric. Quartz grains of silt to fine sand size occur in both the matrix and the intraclasts, constituting up to 10 percent of the total sediment. Opaque to light brown material (bituminous?) occurs in some of the intraclasts, and as elongate blobs in the matrix.

The conglomerate has 0.1 to 0.3 m diameter clasts in a closed framework. The clasts are well-rounded and are of white and pink quartzite. Some conglomerates appear "stretched", having a distinct alignment of clasts parallel to bedding, and some of the quartzite clasts have tension cracks filled with quartz. The silty dolomite and conglomerate are often seen in outcrop to be conformably interbedded, with conglomerate beds up to 3 m thick occurring in the silty dolomite. The silty dolomite appears to be the predominating lithology. These rocks dip vertically or sometimes steeply towards the east, and strike north-south. No evidence of small-scale folding was seen.

This dolomite/conglomerate association was observed in the New River gorge immediately north of the New River depression, which was not visited but can be tentatively assumed to contain the same dolomitic rocks.

Age Relationships

The phyllite and quartzite units observed in the New River gorge and on the high ridge north of the gorge are presumed to be Precambrian on the basis of their similarity to Precambrian rocks elsewhere in Tasmania. The silty dolomite/conglomerate association shows less evidence of deformation, and may therefore be a younger unit than the phyllites and quartzites. By comparison with dolomitic sediments elsewhere in Tasmania, the dolomite/conglomerate association may be of Late Precambrian to Cambrian age. However, the absence of facings, fossils or other evidence makes it difficult to assess the age relationships of the units in the New River gorge.

Age Unknown

An outcrop of well-bedded rock occurs on the New River at DM640990, below the gorge. A cursory examination showed that it was clearly neither conglomerate nor limestone. It dips approximately 30° towards the south or southeast.

No other definite bedrock outcrops were identified on the New River from this point downstream to just above the Salisbury River junction.

?Late Cambrian to Ordovician

?Denison Group Conglomerates

From approximately DM645983 downstream to the Salisbury River confluence, many large boulders of reddish conglomerate, similar in appearance to Denison Group conglomerates elsewhere in Tasmania,

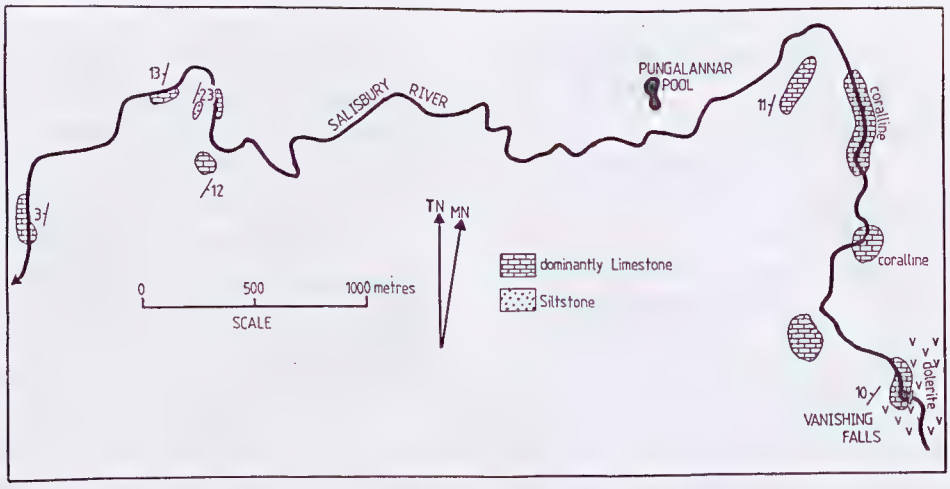

FIG.2 — Detail map showing Ordovician Gordon Group limestone outcrop localities, Salisbury River.

occur in the bed and banks of the New River. None of these boulders was obviously bedrock, and most were clearly allochthonous boulders. A supposed bedrock outcrop of this conglomerate recorded in Burrett *et al.* (1981) is possibly allochthonous, since a bedrock outcrop of dolomite occurs very close to the reported conglomerate "outcrop" location (see below). On topographic and structural (see Regional Structure) grounds it is likely that the conglomerate boulders are derived from a ridge immediately west of the section of river in which the boulders occur.

Gordon Group Carbonates

Carbonate rocks correlated with the Ordovician Gordon Group occur on both the New and Salisbury Rivers. New River: At DM643958, on the New River just upstream of the Salisbury River confluence, a block of dolomite 5 m long is probably an outcrop. It is exposed beneath river gravels in the west bank of the river. No macrofossils were seen, but the rock has a similar field appearance to Gordon Group limestones elsewhere in Tasmania, and Gordon Group limestones occur on the Salisbury River nearby.

The rock is medium grey, with slightly undulose bedding defined by light and dark bands 5 to 20 mm thick. The bedding is disrupted in places by small autobrecciation fractures along which the rock tends to break. The bedding is vertical or sub-vertical, striking 224° True; facing is unknown.

Specimen UTGD 68101 is a uniform sparry dolomite (anhedral interlocking grains 0.1 to 0.2 mm in diameter) with no allochems or sedimentary structures apart from one slightly undulose 3 mm thick lamination of dolomicrite containing some spar and a few scattered quartz grains averaging 0.5 mm in diameter. Fine fractures, randomly oriented, occur throughout the specimen, and one fracture offsets the dolomicrite lamination. Dissolution of part of the sample failed to yield identifiable conodonts, although possible deformed conodonts are present (C. F. Burrett, *pers. comm.*) Salisbury River: Limestone of the Gordon Group crops out discontinuously in the Salisbury River valley downstream from Vanishing Falls to DM660965 (fig. 2). The top of the section is terminated by a dolerite sill at Vanishing Falls.

The total thickness of Gordon Group rocks is unknown due to lack of outcrop and apparent folding in the middle Salisbury valley. Time and weather considerations precluded any detailed observation of macrofossils and structures during this study. Nevertheless some generalisations can be made.

A stratigraphic section is illustrated in fig. 3. The lowermost exposures consist of massively-bedded micrite, with calcareous mudstone beds occurring higher in the section. This is overlain by a 2 to 3 m thick, bedded siltstone unit, which is immediately overlain by interbedded dolomicrite and calcareous mudstone. A sample collected near here a decade ago contained a conodont fauna of middle-Late Ordovician age, as well as scolecodonts, chitinozoa and graptolite fragments (Burrett 1978 and *pers. comm.*).

A section of limestone, approximately 100 m thick, is exposed in the 2 km long gorge below Vanishing Falls. At DM700972 this consists of apparently unfossiliferous micrite. This is overlain by about 40 m of coralline limestone. This unit contains colonies

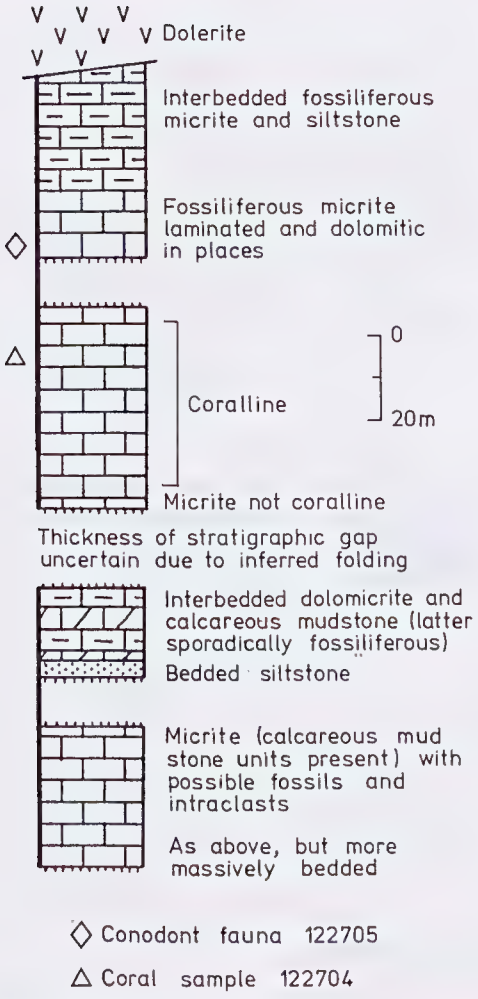
Dolerite
Interbedded fossiliferous micrite and siltstone
Fossiliferous micrite laminated and dolomitic in places
Coralline
0
20m
Micrite not coralline
Thickness of stratigraphic gap uncertain due to inferred folding
Interbedded dolomicrite and calcareous mudstone (latter sporadically fossiliferous)
Bedded siltstone
Micrite (calcareous mud stone units present) with possible fossils and intraclasts
As above, but more massively bedded
Conodont fauna 122705
Coral sample 122704

FIG.3 — Geological column: Gordon Group, Salisbury River.

of *Palaeofavosites* sp. (sample UTGD 122704), similar to Kenna's (1978) species A, suggesting an age similar to that of the top of the Benjamin Limestone from the Florentine Valley (M.R. Banks, *pers. comm.*). The colonies are up to 0.7 m in diameter, in some cases no more than 1 m apart, and are often spectacularly exposed in water-polished riverbed outcrops. Small gastropods were observed between the colonies.

The coralline unit is overlain by a styolitic, silty, fossiliferous micrite. This probably represents greater detrital deposition post-dating the demise of the "reef". This unit (sample UTGD 122705, grid reference DM701958) contains stictoporid and trepostome bryozoa (including *Rhombotrypa* sp.), a few shelly fragments (including strophomenid brachiopods) and numerous echinoderm fragments. The matrix is relatively uncalcitic, consisting predominantly of quartz, sericite and shell fragments. A small tourmaline clast, an epidote (?) grain and rhombs of ferroan carbonate were noted. The sample shows little recrystallisation, and the echinoderm plates are some of the least altered of any Tasmanian Ordovician samples (M.R. Banks, *pers. comm.*).

A conodont fauna separated from sample UTGD 122705 contains *Oulodus* sp., suggesting an upper Middle to lower Upper Ordovician age, and also contains abundant probable conularid fragments. This fauna is similar to that occurring in coralline limestone in the Picton River, 20 km to the north (C.F. Burrett, *pers. comm.*).

The coralline unit appears to grade upward into interbedded fossiliferous micrite and siltstone occurring

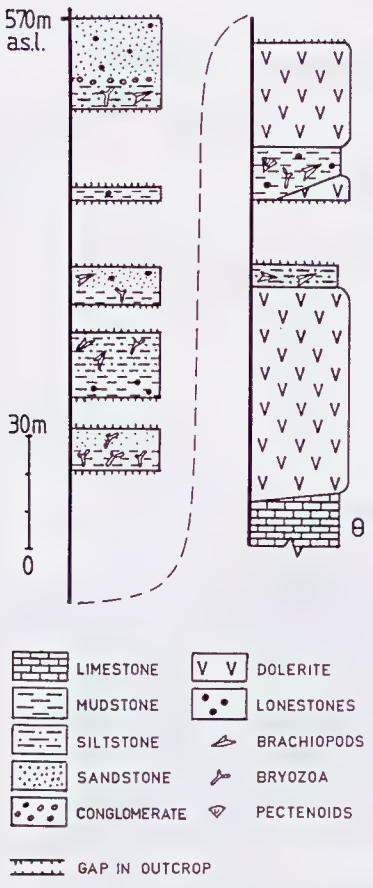

FIG.4 — Geological column: Parmeener Supergroup, Jurassic dolerite, upper Salisbury River.

at the base of Vanishing Falls. Here the limestone is virtually a calcsilicate hornfels for at least 5 m below the dolerite intrusion. A similar hornfels occurs adjacent to dolerite at Lake Sydney and has been interpreted as a correlate of the Eldon Group (Correy 1983). The more siliceous rocks at the base of Vanishing Falls may correlate with the base of the Eldon Group.

Burrett *et al.* (1984) suggest that deepening exhibited at Precipitous Bluff and the shallowing observed in the south coast carbonates happened isochronously in about Kirkfieldian time and indicate a substantial decrease in the depositional slope over a wide area of southern Tasmania. The New River Beds (Burrett *et al.* 1981) contain corals of sufficient abundance that the designation "reef" may be appropriate (Burrett *et al.* 1984). Similar "reefal" limestone near Vanishing Falls is significantly younger. It is likely that a landward migration (i.e. constant depth) of the reef during the transition of the Tasmanian platform from a rimmed shelf to a ramp (Burrett *et al.* 1984) occurred. The occurrence of still younger coralline limestone in the Picton River 20 km further north (Burrett 1978 and *pers. comm.*) may be significant in this regard.

Late Palaeozoic

Flat-lying sedimentary rocks of the Parmeener Supergroup (Banks 1973) crop out in the Salisbury River from DM715914 to DM692886 (fig. 1). In this area the river flows for up to several hundred metres over bedding planes, before descending in small cascades to further such planes. A stratigraphic section is illustrated in fig. 4. In general, the upper part of the section is less fossiliferous than the lower part.

In the vicinity of DM706950 outcrops of fossiliferous siltstone and mudstone are intruded by dolerite. The sedimentary rocks contain brachiopods, bryozoans (mostly fenestellids) and pectenoids, and are wellbedded. The fossil abundance varies significantly from bed to bed. The mudstone contains sparse quartzite lonestones up to 40 mm in diameter.

Upstream from DM715914 to DM701893 the Parmeener Supergroup consists of layers of richly-fossiliferous siltstone and poorly fossiliferous, usually dark mudstone. A low species diversity was noted (mainly *Fenestella* and strophomenid brachiopods). Rounded quartzite and quartz schist lonestones up to 50 mm in diameter are common in the mudstone and the less fossiliferous siltstone.

At DM693887 well-bedded, grey, fenestellid siltstone is overlain by a "graded" conglomerate bed 1 m thick. In addition to *Fenestella,* the siltstone contains a few small brachiopods and, rarely, gastropods 20 mm in whorl diameter. The conglomerate is polymodal, with clasts of quartzite, quartz schist and conglomerate up to 150 mm in diameter. Overlying the conglomerate irregular thick beds of sandstone with quartzite and quartz schist lonestones, usually subangular and up to 150 mm in diameter, crop out for about 200 m.

Jurassic

At Vanishing Falls (grid reference DM705955) the river plunges 70 m over a sill-like dolerite intrusion of presumed Jurassic age. The dolerite intrusion separates the Gordon Group limestones below from the Parmeener Supergroup rocks above. The latter are intruded again by dolerite upstream of the Falls (see fig. 4).

The dolerite crops out as an escarpment at Vanishing Falls, and discontinuously as riverbed outcrops for some 2 km upstream. Just north of Vanishing

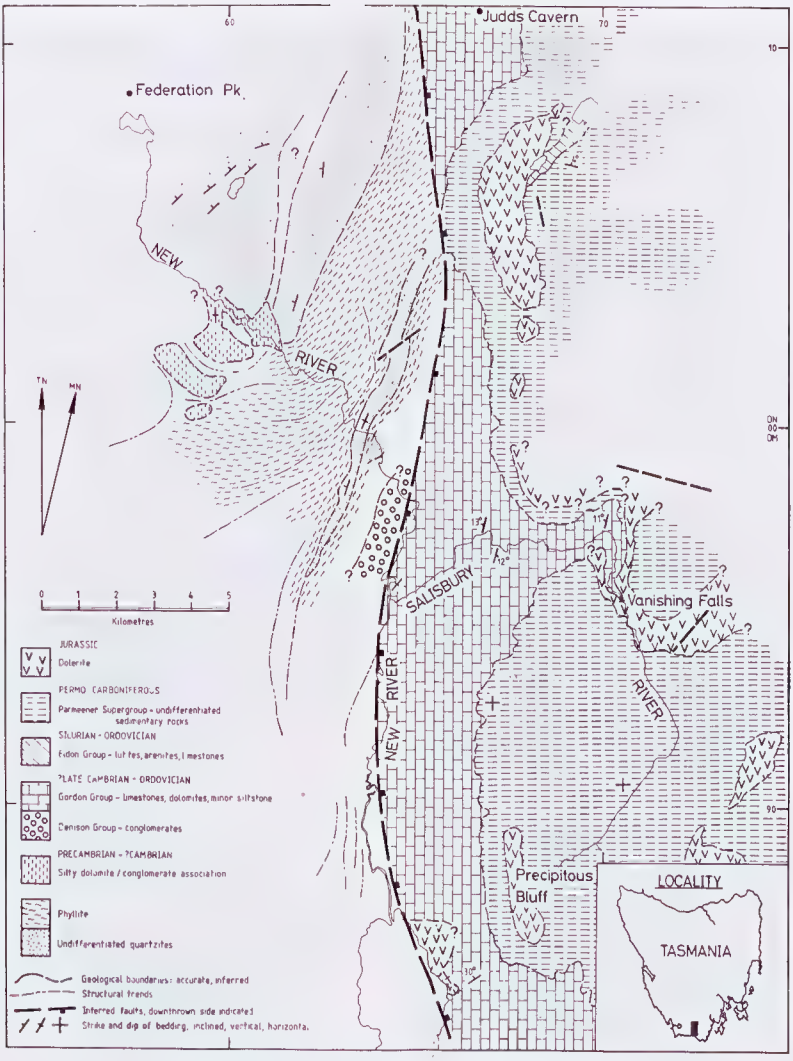

FIG.5 — Interpretive geological map of the New and Salisbury Rivers area, compiled from information in this paper, airphoto interpretation, Burrett et al. *(1981) and Correy (1983).*

Falls, the base of the dolerite sill appears to transgress to higher topographic levels on the west side of the Salisbury River.

Quaternary

No outcrop was observed in the New River bed below the Salisbury River junction. The river cuts through alluvium deposits containing predominantly dolerite cobbles and boulders. A few boulders of grey matrix-supported mixtite (Late Palaeozoic tillite ?) were noted within 1 km or so below the Salisbury River junction.

REGIONAL STRUCTURE

Using airphoto interpretation in conjunction with ground information it is possible to construct a map of the regional structure (fig. 5). The most outstanding structural feature of the area is the approximately linear geological boundary marked by the lower-middle New River and the southern watershed of the Cracroft River. On the west side of this boundary Precambrian rocks occur at the same topographic levels as the Palaeozoic and Jurassic rocks on the eastern side. Whereas this could result from the Palaeozoic rocks lapping

onto a Precambrian basement high, it has been suggested (Corbett 1970 and Burrett *et al.* 1981, p.98) that the geological boundary is the site of a major transcurrent fault. Burrett *et al.* (1981) suggest that vertically-dipping limestone at New River Lagoon and a shear zone at Point Cecil (south coast) support the existence of such a major fault (Berry & Harley 1983, Bischoff 1983). In addition, the vertical dip, possible deformed conodonts and intense fracturing evident in the dolomite near the confluence of the New and Salisbury Rivers support major fault movement.

Whilst transcurrent movement along the postulated fault has not been proved and the amount of hoizontal shift is unknown, vertical movement would need to be of the order of hundreds of metres to account for the juxtaposition of Precambrian and Palaeozoic rocks. The probable existence of Denison Group bedrock west of the New River, above adjacent Gordon Group limestone, can be accounted for by the postulated fault. Based on airphoto interpretation and ground observations, the Precambrian quartzite and phyllite in the New River gorge area strike generally north-northeast, swinging westward southwest of the gorge. The relationship between the dolomite/conglomerate association and the unit of quartzite and phyllite is unclear, and is probably structurally complicated.

The unconformity between the Ordovician limestone and Parmeener Supergroup rocks seems relatively horizontal between Judds Cavern and Precipitous Bluff, occurring at approximately 400 m ASL over most of that distance, although a higher occurrence of Eldon Group rocks at Lake Sydney (Correy 1983) and an apparent lack of Ordovician limestone in the uppermiddle Farmhouse Creek area indicates variations in the unconformity surface east of Mt Bobs.

Precipitous Bluff, Mt Bobs, Bobs Knobs, Mt Bisdee and other mountains east of the New River appear to be erosional remnants of a single dolerite sill. The dolerite at Vanishing Falls crops out at a lower stratigraphic level, and observational and airphoto evidence suggest that the dolerite transgresses upwards from the Vanishing Falls area to join the upper dolerite sill at the southern end of Bobs Knobs.

ACKNOWLEDGEMENTS

We thank C.F. Burrett and M.R. Banks for useful discussions, criticisms and fossil identifications, C. Calver for useful discussions and criticisms, and the Australian and New Zealand Scientific Exploration Society (ANZSES) for making the Salisbury River trip possible.

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(accepted Aug. 30, 1985)

THE WURAWINA SUPERGROUP, LATE CAMBRIAN TO EARLY DEVONIAN, TASMANIA

by M.R. Banks and E. Williams

BANKS, M.R. & WILLIAMS, E., 1986 (21:ix): The Wurawina Supergroup, Late Cambrian to Early Devonian, Tasmania. *Pap. Proc. R. Soc. Tasm.* 120: 95–96. ISSN 0080-4703. University of Tasmania, Hobart, Tasmania and Department of Mines, Rosny Park, Tasmania, Australia.

The term "Wurawina Supergroup" is proposed for the conformable sequence in western Tasmania consisting of the Denison Group, the Gordon Group and the Eldon Group or the Tiger Range Group and their correlates. The Supergroup rests on early Late Cambrian or older rocks and is folded, and then intruded by Late Devonian and Early Carboniferous granites. It is Late Cambrian at the base and Early Devonian at the top.
Key Words: Early Palaeozoic, Tasmania, Supergroup.

INTRODUCTION

Phrases such as "the rocks of the Junee Group and the Eldon and Tiger Range Groups ..." and "The Late Cambrian to Early Devonian conformable succession of sedimentary rocks ..." occur quite frequently in geological literature on western Tasmania, especially in regional review papers. A short term to replace such circumlocutions seems likely to be useful.

BACKGROUND

The Junee Group of Hills and Carey (1949), consists in the main of correlates of the Junee Series of Lewis (1940) and rests, usually with angular unconformity, on early Late Cambrian or older rocks. Corbett and Banks (1975) treated the formations in it as belonging to two subgroups, the Denison Subgroup below and the Gordon Subgroup above. Subsequently Burrett *et al.* (1984) have raised the Subgroups to Group status.

The Denison Group defined in the Denison Range of south-central Tasmania, is a sequence of conformable beds of clastic rocks of Late Cambrian and Early Ordovician age (Corbett 1975). Correlates of the Denison Group contain some disconformities in the lower part and angular unconformities (e.g. Haulage) occur within the lower part of the group (Adams *et al.* 1985). The Denison Group grades up into the Gordon Group.

The Gordon Group defined in the Florentine Valley of south-central Tasmania (Corbett & Banks 1974), and its correlates consist of a conformable marine succession of predominantly carbonate rocks with minor siltstone and fine sandstone ranging in age from Early Ordovician (base) to Early Silurian (top) (Banks & Burrett 1980). The group when first used as a subgroup by Corbett & Banks (1974) excluded the Westfield Beds and this usage was applied to the Group by Burrett *et al.* (1984). However Corbett & Banks (1975) included the Westfield Beds in the Subgroup and this practice is followed here. The unit, the Westfield Beds, has since been included as part of the later-named Arndell Sandstone (Baillie 1979) which was also included in the Gordon Group because the base of the overlying Tiger Range Group (a correlate of the Eldon Group in western Tasmania) is much more readily recognizable in field mapping than the top of the limestone below the Arndell Sandstone equivalents.

In western Tasmania correlates of the Gordon Group are overlain concordantly, but in places with disconformity, by the Eldon Group. In south-central Tasmania it is overlain gradationally by the Tiger Range Group (Baillie 1979). These groups range in age from Early Silurian (base) to Early Devonian (top) (Talent & Banks 1967, Baillie 1979).

The Denison, Gordon and Tiger Range Groups, and their correlates were folded together in Early to Middle Devonian time, overlain unconformably at Eugenana in northern Tasmania by the late Middle Devonian Eugenana Beds (Balme 1960) and intruded in several places by granitic rocks with K-Ar ages ranging from 332 to 367 m.y. (Collins & Williams 1986). The folded intruded rocks are overlain on an erosional surface by Late Carboniferous (or Early Permian, possibly, in places) sedimentary rocks of the Parmeener Supergroup.

DEFINITION

The term "Wurawina Supergroup" is proposed for a unit in western Tasmanian comprising

the Denison Group below the Gordon Group and the Eldon Group or Tiger Range Group above, bounded basally by an unconformity, and overlain with angular unconformity by the Parmeener Supergroup of Late Carboniferous to Triassic age. The Supergroup is Late Cambrian at the base and Early Devonian at the top.

DERIVATION OF NAME

Wurawina is the name of a lake in the Denison Range in south-central Tasmania. Its geographic co-ordinates are 146° 16′43″E, 42° 32′24″S (Australian Map Grid Zone 55 DN408901). It lies in an area dominated by units of the Supergroup.

DISCUSSION

It is appropriate to apply the term Supergroup to this unit as it consists of an essentially conformable succession of sedimentary rocks, some formations within which have already been aggregated into Groups.

ACKNOWLEDGEMENTS

The authors glady acknowledge the helpful discussions held with Dr Clive Burrett, University of Tasmania. E. Williams published with permission of the Director of Mines, Tasmania.

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(accepted Mar. 10, 1986)

AN EARLY LATE CAMBRIAN FAUNA FROM TOM CREEK, WESTERN TASMANIA

by J. B. JAGO

(with one plate)

JAGO, J.B., 1986 (12:ix): An early Late Cambrian fauna from Tom Creek, western Tasmania. *Pap. Proc. R. Soc. Tasm.* 120: 97–98, 1 pl. ISSN 0080-4703. South Australian Institute of Technology, P.O. Box 1, Ingle Farm, South Australia 5098.

A small, poorly preserved, but stratigraphically significant fauna from Tom Creek in western Tasmania contains the trilobites *Agnostardis* and *Aulacodigma* which indicate correlation with the upper part of the Brewery Junction Formation in the Dundas area and an age of very early Late Cambrian Glyptagnostus stolidotus Zone.
Key Words: trilobites, Late Cambrian, Tasmania.

INTRODUCTION

A very early Late Cambrian fauna from Tom Creek, western Tasmania, is small and poorly preserved but stratigraphically important in that it is the only Cambrian fauna in the Dundas Group of the Farrell Rivulet area on which a reliable date can be obtained. The Cambrian geology of this area is being revised (Corbett & Lees, in prep.).

A. B. Gulline discovered the fossils figured herein in a cleaved, grey, laminated siltstone in Tom Creek near lat. 41° 55.5'S, long. 145° 26.3'E (Blissett 1962). The position of the fossil locality is shown on the Zeehan 1-mile geological map sheet (Blissett 1962). Gatehouse (1961) considered the fossils to be late Middle or early Late Cambrian age. The only other record of the Tom Creek fauna is that in Banks (1982).

The known fauna is limited to one agnostoid cephalon, two agnostoid pygidia, an essentially complete small polymeroid trilobite, the cephalon of a polymeroid and some polymeroid fragments. All specimens are too poorly preserved to warrant formal description. All the agnostoids are tentatively placed in the one species of *Agnostardis*. The two identifiable polymeroid specimens belong in the same species of *Aulacodigma*. In the Georgina Basin of northern Australia both these genera are confined to the very early Late Cambrian *Glyptagnostus stolidotus* Zone (Öpik 1963, 1967), which age is thus suggested for the Tom Creek fauna. This fauna is hence a correlate of the faunas found in the upper 50 m of the Brewery Junction Formation in the Dundas Group type section at Dundas (Jago 1979). All catalogue numbers refer to the collection of the Geology Department, University of Tasmania.

PALAEONTOLOGY

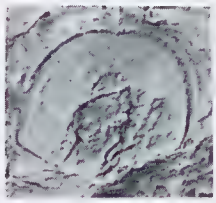
Class TRILOBITA Walch 1771
Order MIOMERA Jaekel 1909
Superfamily AGNOSTACEA M'Coy 1849
Family DIPLAGNOSTIDAE Whitehouse 1936
Genus *AGNOSTARDIS* Öpik 1963

Agnostardis sp.
(Plate 1, figs 1-3)

One cephalon and two pygidia are available. These specimens are placed with some hesitation in a single species of *Agnostardis*. The glabella of the cephalon is obscured. The preglabellar median furrow is only faintly developed in contrast to those in most of the cephala of *Agnostardis* figured in Öpik (1963, 1967). However, it is similar to that shown by the cephalon of Agnostardis figured by Opik (1967, pl.41, fig.9a).

Although the two agnostoid pygidia figured herein are tentatively referred to a single species of *Agnostardis*, there appear to be considerable differences in the shape of the pygidial axes. However, the pygidia of *Agnostardis amplinatus*, illustrated by Öpik (1963, pl.3), show considerable intraspecific variation as well as having different appearances depending on the preservation.

Unlike all illustrated pygidia of *Agnostardis amplinatus* there does not appear to be a well-developed post-axial median furrow in UT54926 (pl.1, fig.3). The pygidial axis in this specimen is much narrower than that in specimen UT54928 (pl.1, fig.2). The junction of the middle axial segment and the posterior bulb in specimen UT54928 is placed further back than in any other illustrated specimen of *Agnostardis* although there does appear to be considerable variation in the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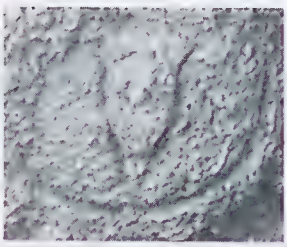
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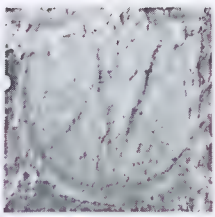
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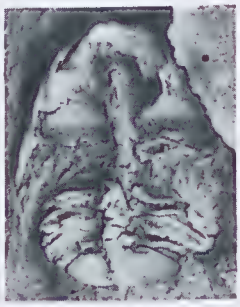
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PLATE 1

Figs 1–3: Agnostardis *sp*
1. *UT54821, internal mould of cephalon, x8*
2. *UT54928, external mould of pygidium, x20*
3. *UT54926, internal mould of pygidium, x8.5*

Figs 4-5: Aulacodigma *sp.*
4. *UT54929, external mould of cranidium and librigena, x10*
5. *UT54929, external mould of almost complete specimen, x7.*

All specimens were whitened with magnesium oxide prior to photography. The external moulds are silicone rubber.

position of this point in *Agnostardis amplinatus* (see Öpik 1963, pl.3; Öpik 1967, pl.67). It should also be noted that UT54928 is much smaller than UT54926 and has been distorted in a different manner.

Order PTYCHOPARIIDA Swinnerton 1915
Family AULACODIGMATIDAE Öpik 1967
Genus *AULACODIGMA* Öpik 1967

Aulacodigma sp.
(Plate 1, figs 4,5)

Two poorly preserved external moulds are available. One of these comprises the cranidium and one librigena, parts of five thoracic segments and the pygidium; the other specimen comprises most of a cranidium and a librigena. As far as can be seen from the available material, these specimens are close to *Aulacodigma quasispinale* Öpik, the type species of the genus as illustrated by Öpik (1967).

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PAPERS AND PROCEEDINGS OF

The Royal Society of Tasmania

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Edited by M. R. Banks and S. J. Smith

and Published by the Society

Hobart, Tasmania

June 1987

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This volume is dedicated to
His Excellency Sir James Plimsoll, AC CBE
25 April 1917—8 May 1987
Governor of Tasmania
and
President of the Society
1982-1987

A. B. CAUDELL, Government Printer, Tasmania

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PAPERS AND PROCEEDINGS OF THE ROYAL SOCIETY OF TASMANIA

Volume 121

31 AUG 1987

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ROYAL SOCIETY OF TASMANIA
ANNUAL REPORT FOR THE YEAR 1986

The Council has the honour to present to members the following report on the activities of the Society during the year.

COUNCIL AND OFFICE BEARERS

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Dr S.J. Smith

President

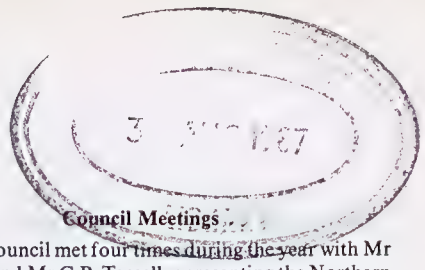
Sir James Plimsoll took the Chair, as President of the Society, at the Annual General Meeting and at the Annual General Meeting of the Northern Branch in March. He also took the Chair at the November General Meeting. He opened the Tasman Peninsula Symposium on 1 November.

Clifford Craig, CMG (1896-1986)

Dr Clifford Craig, CMG, MD, MS, FRACS, DDR, MRACR, died in Launceston on 5 September 1986, aged 90. Dr Craig joined the Society in 1939 and served on the Council of the Northern Branch almost continuously from 1946 to 1963. He was Chairman of the Northern Branch in 1950-51 and 1960-61. He was elected an Honorary Life Member in 1975. The Council places on record its appreciation of his contributions both to the Society and to the history of Tasmania.

Eric Oswald Gale Scott (1899-1986)

Eric Scott died on 25 June 1986 after a road accident near his home in Launceston. Mr Scott joined the Society in 1931. He served the Northern Branch well, particularly during his terms as Honorary Secretary from 1931 to 1937 and from 1939 to 1943. He was a regular contributor to the Papers and Proceedings particularly on Tasmanian fish. The Council places on record its appreciation of his contributions both to the Society and to Tasmanian zoology.



Clive Lord Memorial Medal

At the General Meeting in November, the President presented the Clive Lord Memorial Medal to Mr R.G.H. Green in recognition of his distinguished research in zoology. Previous recipients have been:

1936 Professor L.F. Giblin	1960 Emeritus Prof. V.V. Hickman
1939 Professor J.B. Cleland	1966 Dr Winifred Curtis
1947 Dr H. Thompson	1973 Dr W. Bryden
1951 Professor J. Burke	1977 Dr E.R. Guiler
1958 Mr P.G. Law	1983 Mr N.J.B. Plomley

Honorary Life Members

Mr P.G. Webb, Dr M.R. Banks and Mr D.R. Gregg were elected Honorary Life Members in recognition of their service to the Society. Mr Webb has served on the Council of the Northern Branch since 1972. He was Honorary Secretary of the Branch from 1978 to 1983 and was Chairman for 1986. Dr Banks has served as Honorary Editor to the Society since 1973. In 1978 he was awarded the Royal Society of Tasmania Medal. He served on the Trustees of the Tasmanian Museum and Art Gallery, as an appointee of the Society, from 1974 to 1984. Mr Gregg has been Honorary Secretary of the Society since 1972.

Annual Meeting

At the Annual Meeting on 4 March, Mr I.D. Geard retired as Vice-President and Dr P.G. Quilty and Dr S.J. Smith as Members of the Council. The following were elected:

Vice-President	Dr P.G. Quilty
Members of Council	Dr J.S. Rogers
	Mr R.D. Shepherd
Honorary Secretary	Mr D.R. Gregg
Honorary Treasurer	Mr T.A.H. Knight
Honorary Auditor	Mr R.J. Dwyer

Membership

The Membership is 431, a decrease of 7, and is made up as follows:

	Northern Branch	Total
Honorary Life Members	3	8
Life Members	11	34
Ordinary Members receiving the Papers and Proceedings	60	260
Ordinary Members not receiving the Papers and Proceedings	57	110
Associate members	15	19
	146	431

Council Meetings

The Council met four times during the year with Mr P.G. Webb and Mr C.B. Tassell representing the Northern Branch on the Council.

Tasman Peninsula Symposium

A symposium was held at Port Arthur from Saturday, 1 November, to Monday, 3 November, on the theme of "Is history enough? Past, present and future uses of the resources of the Tasman Peninsula." Seventy-two people attended the opening session during which the guest speaker, Dr Lloyd Robson, University of Melbourne, delivered the keynote address. Other addresses dealt with geology, geomorphology, water resources, botany, zoology, shoreline and shallow marine ecology, archaeology, history, forestry, agriculture, fishing, pisciculture, landscape as a resource, tourism and future prospects. Excursions were conducted to the Saltwater River area, Eaglehawk Neck and Fortescue Bay area, Port Arthur, Standup Point and a fish farm at Nubeena. It is planned to publish the addresses during 1987. The symposium was run at a small financial profit. Those participating from both the Northern Branch and southern Tasmania expressed appreciation and the main profit to the Society was in terms of better communication between members. The publication of the Symposium should provide valuable publicity for the Society.

The Society is indebted to Dr M.R. Banks and the other members of the organising committee, Dr B. Egloff, Mr D.C. Hannan, Dr. S.J. Smith and Mr L.E. Wall.

Sir Joseph Banks Memorial Lecture

The Council continued to plan the 1988 lectures to be given in all Australian State capitals, Canberra and London. Sponsorship has been obtained for travel and the itinerary has been finalised. The project has been endorsed by the Australian Bicentennial Authority.

Library

The year was marked by a change in Librarian. Mrs G. Thavisin was transferred to another position within the University Library and her transfer marked the end of her very capable contribution to the Society's Library. In August, Mrs B. Chalmers was appointed to replace Mrs Thavisin. The maintenance of the previous level of part-time clerical assistance permitted the continued staffing of the library from 9 am to 5 pm on weekdays. Reference staff of the University Library also assisted in staffing when required.

Visitors during the year totalled 428. The value of the collection is reflected in the use made by University staff and students and members of the Society. Queries continue to reflect the high regard researchers have for the collection. There were 151 requests for interlibrary loans, and 79 loans of periodicals were made to individual users.

As mentioned in the last report the large backlog of binding that had existed for many years was almost eliminated by the end of 1985 and consequently there was

some reduction in the level of binding in 1986. A total of 416 volumes was bound during the year.

Early in the year a check was made of the Closed Access room and the Rare Book collection. The check revealed a need for some re-arrangement of these areas, and the re-arrangement was subsequently put in hand.

Significant additions to the Library this year have included:

THE ROYAL TASMANIAN BOTANICAL GARDENS; by Marcus Hurburgh — donated by the author.

DIARIES AND LETTERS OF G.T.W.B. BOYES, VOL. I; edited by P. Chapman — donated by Oxford University Press.

Both authors made use of the Royal Society library and Archives in compiling material for inclusion in these works.

Volume 120 of the Papers and Proceedings was published during the year, and in October copies were distributed to 302 exchange partners throughout the world. Later in the year the author/subject index (in card form) to this volume was completed and was distributed to eight Tasmanian libraries.

Royal Society Room

Renovations to the Royal Society Room at the Tasmanian Museum and Art gallery were carried out by the Trustees. The General Meetings in May, June and July were held in one of the art galleries.

Publications

Volume 120 of the Papers and Proceedings was published in September 1986. It contained 12 papers, involving 20 authors and covering botany, geochronology, geology, geomorphology, ichthyology, meteorology, ornithology and palaeontology. The papers occupied 98 pages. A whiter paper than usual was used and improved the readability and appearance of the volume. Regrettably some errors were made in collation of the volume resulting in some volumes being imperfect. Steps have been taken to prevent a recurrence.

The Society is once more indebted to Dr Banks and Dr Smith for their dedicated work as editors.

Lectures

The following lectures were given at General Meetings during the year:

March — "Charles Darwin in Hobart Town, 1836" Dr M.R. Banks, University of Tasmania

April — "Medieval Science and Modern Physics, the investigations of Duns Scotus" Rev. Dr J. Wall, University of Tasmania

May — The Biological Consequences of Isolation (Joint meeting with Tasmanian Branch of the Institute of Biology in Australia) "The Effects of Isolation on Australia's Fauna" Professor D.M. Stoddart, University of Tasmania
"The Effects of Isolation on Human Disease in Australia" Dr J.M. Goldsmid, University of Tasmania

June — "Recent Studies on the Arboreal Marsupial Fauna of southeastern (mainland) Australia and thir Application to Forest Management in Tasmania" Mr Tony Norton, Australian National University

July — "Two months on Heard Island, Seals, Sealers, Vegetation" Mr Harry Burton, Antarctic Division, and Miss Joscelyne Hughes, University of Tasmania

August — "Local Defence Mechanisms and Early Cancer" Professor H. Konrad Muller, University of Tasmania

September — "Could Fish use Inertial Navigation?" Dr Roy Harden Jones, CSIRO

October — "The Influence of Modern Surgical Treatment on the Outcome of Primary Intracranial Haemorrhage" Dr Graeme Duffy, Neurosurgeon

November — Clive Lord Memorial Lecture "Reactions of the Tasmanian Fauna to Foreign Invasion" Mr R.G.H. Green, Queen Victoria Museum

A visit was arranged to Mt Nelson on 13 April to observe Halley's Comet under the guidance of Mr Stefan Dieters of the Physics Department, University of Tasmania.

Northern Branch

Chairman	Mr P.G. Webb
Vice-Chairman	Mrs R.M. Cameron
Past Chairman	Mrs G.M. Morris
Honorary Secretary	Mr C.B. Tassell
Honorary Treasurer	Mr K.E.J. Robinson
Council Members	Dr J.C. Standard
	Mr D.G. Hannan
Branch Representatives on the Council	Mr P.G. Webb
	Mr C.B. Tassell

The Branch Council met four times during the year.

The following lectures were given at General Meetings:

March — "Whale Strandings in Tasmania" Mr B.L. Munday, Department of Agriculture

April — "Wine Production in Tasmania" Mr F. Peacock, Department of Agriculture "Pipers Brook

Vineyard and Winery" Mr Graham Wiltshire, Heemskirk Wines

May — "History of the Cycle" Dr J.K. Cannell, Design and Research Consulting Engineer

June — "Recent Studies on the Arboreal Marsupial Fauna of southeastern (mainland) Australia, and their Application to Forest Wildlife Management in Tasmania" Mr Tony Norton, Australian National University

July — "The Tasmanian Tertiary Flora" Mr Tony Bigwood, Plomley Fellow at the Queen Victoria Museum and Art Gallery

August — "Australian Research in Antarctica" Dr Patrick Quilty, Antarctic Division, Department of Science

September — "Arboreta and the Tasmanian Arboretum at Eugenana" Dr Walter Barrows, International Society of Arboretists

October — No meeting. Instead, Branch Council decided to ask members to attend the Eldershaw Memorial Lecture, delivered by Professor Enid Campbell on 15 October

November — "Banking in the 1980s" Mr Ian Warwick, Westpac

December — Members' Night
"The 900th Anniversary of the Doomsday Book" Mrs G.M. Morris
"Reading of the "*Ballad of Father Riley's Horse*" by A.B. Paterson" Mr R.E. Ward
"Surviving in Spain in the 60s" Mrs J. Sebbage
"Inns and Outs" Mr A.T. Orr

Excursions

Saturday, 5 April — Tour of Pipers Brook Winery, conducted by the owner, Mr Graham Wiltshire, producer of Heemskirk Wines

Saturday, 13 September — Excursion to the Tasmanian Arboretum at Eugenana, hosted by the Arboretum Society and tour of the site conducted by visiting arboretist Dr Walter Barrows of the International Society of Arboretists

Weekend, 1-3 November — Tasman Peninsula Symposium. The Northern Branch co-operated in organising the symposium; Mr D.G. Hannan joined the organising committee and a number of members from the north took part.

Nominees to Other Bodies

The Council re-elected Mr A.R. Neilson and Dr P.G. Quilty to serve a further term on the Board of Trustees of the Tasmanian Museum and Art Gallery. They report on the year's activities:

The 1986 State Budget provided $1 197 300 to the Tasmanian Museum and Art Gallery, an increase of 3.4% over the allocation in the 1985 budget. This increase is below that predicted for inflation. About 82% of the allocation will be spent on salaries and related costs. The Government grant is seen by the Trustees as substantially less than the demonstrable need of the Museum and Art Gallery.

By Government decision, the three Education Officers based at the Museum and Art Gallery are to be reduced to two in 1987.

The renovation of the Queens Warehouse and the construction of the new entrance building in Macquarie Street were virtually completed at the end of 1986. The Royal Society room has been renovated.

Funds have been included in the 1986 Budget to build a new building for the Tasmanian Herbarium on the University of Tasmania Sandy Bay campus.

The Art Foundation of Tasmania continued to encourage support from the private sector for acquisitions for the collections of the Museum and Art Gallery. The Foundation has provided funds to enable the following purchases to be made:

The Artist and Geelong Memorial Figure by G.W. Lambert, c.1924, oil on board
Julia Sorell by T. G. Wainewright, c.1846, watercolour
Lloyd Rees by Stephen Walker, 1984, bronze
Self portrait by Nora Heysen, 1933, oil on canvas.

The Friends of the Tasmanian Museum and Art Gallery Inc. provided funds to assist with the purchase of the portrait of Julia Sorell, and to puchase a Tasmanian halfpenny token and a set of rings by Phill Mason. The Friends also assisted with funds to publish the catalogue for the Prout exhibition.

During the 1986 year, 132 682 people visited the Tasmanian Museum and Art Gallery, compared with 119 634 in 1985. The annual number of visitors to the West Coast Pioneers' Memorial Museum, Zeehan is estimated at 119 000.

A selection of watercolours by Simpkinson De Wesselow (1819-1906), from the Royal Society collection, was shown at the Geelong Art Gallery in May and June.

An active programme of temporary exhibitions took place during the year, and this included *Sullivans Cove, Birthplace of a Colony* (November 1985-April), *Selected British Art from the Collection* (December 1985-February), *Lloyd Rees as Printmaker* (February-April), *Robert Richmond Campbell, an Australian Impressionist* (May), *Gladys Blaiberg, Wartime Caricaturist* (May-July), *Tasmanian Watercolours from the Collection* (June-August), *Devils, Drugs and Doctors, a Wellcome History of Medicine* (July-September), *Francis Lymburner Drawings* (August-September), *Michael*

Shannon (October), *People of the Cedar* (October-November), *The Rome Connection, Prints from XVII Century Europe* (November), *Nature Prints* (November-January 1987) and *Skinner Prout in Australia 1840-48* (December-January 1987).

Devils, Drugs and Doctors was the first exhibition for which an entrance fee was charged. The money collected went to the International Cultural Corporation of Australia, organisers of the exhibition. During its 46 day showing, the exhibition was visited by 26 631 people. A total of 45 618 people visited the Museum and Art Gallery during the exhibition; last year 16 000 people were counted during the comparable 6 ½ weeks.

Dr J.E.S. Townrow was re-elected by the Council to serve a further term on the Board of Trustees of the Royal Tasmanian Botanical Gardens. She reports on the year's activities:

Nineteen hundred and eighty-six has been a year of mixed fortunes for the Gardens.

Public patronage apparently dropped by 5% to 236 000. The lower number of recorded visitors may be linked with the decline in the tourist trade and the more stringent economic climate. However the drop may be more apparent than real because the main gates which are not monitored were open for construction traffic from mid November to the end of December and several thousand visitors were not counted.

The Museum's opening hours were extended to 10 am to 4 pm (summer Monday-Friday) and 11 am to 3 pm (winter). Major displays included *Grasses*, followed by *Eucalypts*, a newly designed *Evolution* room and a basket weaving exhibit. Even so the Museum visitors (19 000 or 8% of the Garden's visitors) were 19% down on last year though school visits were up 34%. One hundred and sixteen schools, including two from Melbourne, and 4 600 pupils compared with 36 schools and 3 500 pupils in 1985.

The State Government Grant was $880 000, a cut of $112 000 on budget estimate of which $706 500 was for wages and salaries, leaving $173 500 for maintenance and general operations. Due to the stringent Government policy of cutbacks in funding and non-filling of vacancies, a reduction in staff to three short of the lowest workable complement was unavoidable, resulting in a noticeable deterioration in maintenance of the Gardens over the past twelve months. The Nursery has been particularly understaffed running on half its full complement for most of the year. Consequently the Conservatory will close 6 weeks early missing out on the Chrysanthemum display. Two annual beds have been grassed over and weeding, edge-trimming and disease control have also suffered because of insufficient numbers of gardeners. Two major landscaping projects — the endemic plant section and the lily pond rockeries reconstruction — have had to be postponed indefinitely because of lack of both staff and finance.

Staffing problems have ben compounded through the introduction of a 38 hour working week, giving wage workers one day off per month.

On a brighter note, the year has been notable for support coming from both public and private individuals. Sir James Plimsoll has been most interested in the Gardens and is a frequent visitor often to be seen showing Gardens highlights to his guests. Our Minister, Hon. P.C.L. Hodgman, MHA, has given great support and been extremely positive working to avoid further Government funding cuts, and expressing enthusiastic appreciation of Gardens developments. The Cabinet, on one of its regular sitting days, lunched with the Board of Trustees for the first time ever at the Gardens, and members were taken on a lightning tour through the rain by the Superintendent in the Horticultural Therapy Minibus.

There has been more than the usual numbers of letters of appreciation from overseas and interstate visitors.

At last, after more than ten years of continued efforts by the Trustees and staff to get Government support and funding, Stage 1 of the reconstruction of the Technical Support Services Centre (formerly the condemned stores and depot area) commenced at the beginning of December.

The Horticultural Therapy unit run by Pat Hewitt has received $70 000 from the Health Department from HACC funds for the development of a Demonstration Garden. This will be part of the Easy Access Garden facility where disabled people will be able to plant and grow flowers and vegetables in a screened outside area behind the Easy Access glasshouse.

The provision of an Education Centre to house classes conducted by Alan Gray, Education Officer, and Pat Hewitt, Horticultural Therapist, has moved closer to reality through the combined efforts of a group of student architects from the Tasmanian State Institue of Technology and Trustees applying for Foundation funding.

Four students led by Mrs Lynden Aylif prepared an excellent design plan and model of the proposed centre with a full report to supplement their design submission for Elective Studies. This splendid start has been boosted by a donation of $10 000 from the Ian Potter Foundation towards the estimated cost of $230 000.

Other notable highlights include progress on the almost completed Japanese garden with continued CEP funding and very generous public donations of money and time. For example, Hobart Technical College staff and students built the Huon Pine waterwheel which was financed by a Hobart businessman, the bridge posts were turned by a HTC tutor, and the various stone lanterns have been donated by several Hobart firms. The opening of the Japanese Garden is planned for 18 February 1987.

The introduction of guided early morning Birds and Plants Walks, followed by breakfast in the gardens restaurant, (another of the Superintendent's brilliant ideas), has proved most popular, and brought more of the community into the Gardens. Another well received innovation was the Tulip Festival when about 4 000 inspected the displays in the Conservatory and the outside beds, and purchased tulips brought in and distributed by costumed members of the Dutch Community.

Many of the public have appreciated the increased numbers of labelled plants, now over 7000 compared with 2500 last year, the good work of Plant Recording Officer, Mrs Sue Wells.

Due to lack of finance, the Trustees were unable to publish the history of the Gardens by Mr Marcus Hurburgh. He financed his own publication and The Royal Tasmanian Botanical Gardens 1818-1986. A History in Stone, Soil and Superintendents, printed by Shearwater Press, is now available.

The Board of Trustees commend the Superintendent Tony May and his staff for their continued devotion to the gardens over the past rather testing year.

Acknowledgements

The Council is grateful for help generously given by many individuals and organisations. In particular, the lecturers, the Government of Tasmania, the University of Tasmania, the Tasmanian Museum and Art Gallery and the Queen Victoria Museum and Art Gallery are specially thanked for their help and co-operation.

P.W. McCarthy
Senior Vice-President

D.R. Gregg
Honorary Secretary

5 February 1987

ROYAL SOCIETY OF TASMANIA

Statement of Receipts and Payments for the year ended 31 December 1986

General Account

Balance 1 January 1986		15 987.94	Stationery	251.13
			Insurance	246.24
Subscriptions			Attendants' fees	614.52
1 @ $200	200.00		Secretarial fees	2 074.36
252 @ $ 12	3 028.00		Post box rental	115.00
102 @ $ 8	822.00		Postage and freight	1 127.68
16 @ $ 5	80.00		Photocopying	46.10
Other years	216.00	4 346.00	Subscriptions	856.75
			Repairs and maintenance	991.18
Interest		3 977.43	Federal & State debit tax	25.92
Donations		28.00	Telephone	20.36
Sales of publications and			Northern Branch	1 000.00
Papers and Proceedings		951.78	Sundry expenses	26.00
Treasury grant		1 800.00	Symposium	3 337.22
Subscription refund		75.26		10 732.46
Symposium		3 763.50	Papers and Proceedings	5 429.71
				16 162.17
			Balance 31 December 1986	14 767.74
		$30 929.91		$30 929 91

Papers and Proceedings Account

Balance 1 January 1986	2 155.33	Tax	0.10
Interest	601.00	Balance 31 December 1986	2 756.23
	$2 756.33		$2 756.33

Accumulation Account

Balance 1 January 1985			66 736.73
Add	Net increase in valuation of publications for sale	232.10	
	Net increase in advance subscriptions	31.00	263.10
			66 999.83
Deduct	Decreased cash at bank	296.26	
	Net transfers to Trust Funds	2 238.50	2 534.76
Balance 31 December 1986			$64 465.07

NORTHERN BRANCH

Balance brought forward	1 012.91	Subscriptions to Hobart	179.00
Subscriptions	179.00	Printing and stationery	543.80
Suppers	11.11	Theatre hire	100.00
Grant (Royal Society)	1 000.00	Postage	149.00
Excursions	328.00	Post Office Box	25.20
Bank interest	32.33	Secretarial services	480.00
		Excursions	295.00
		Sundries (badges)	30.00
		Bank charges, etc.	6.00
		Bank balance	755.35
	$2 563.35		$2 563.35

ROYAL SOCIETY OF TASMANIA

Balance Sheet as at 31 December 1986

1985			*1986*
66 736.73	Accumulated Funds		64 465.07
143.00	Subscriptions in advance		112.00
	Trust Funds:		
2 088.03	— Clive Lord Memorial Fund	2 285.03	
3 503.48	— A.N. Lewis Memorial Fund	3 831.34	
1 592.74	— Morton Allport Memorial	1 782.47	
627.36	— A.A. Clark Bequest	683.45	
4 276.70	— Joseph Milligan Bequest	4 676.37	
2 322.54	— R.M. Johnston Memorial Fund	2 543.08	
1 017.26	— Henry Oliver Bequest	1 12.406	
2 328.64	— W.H. Hudspeth Memorial	2 547.66	
3 740.70	— Life Membership Fund	4 274.15	23 735.95
$88 377.18			$88 313.02
	Represented by:		
33.00	Cash on hand		33.00
	Cash at bank:		
15 987.94	— General account		14 767.74
2 155.33	— Papers & Proceedings Account		2 756.23
534.54	— Clive Lord Memorial Fund		672.17
748.87	— A.N. Lewis Memorial Fund		934.28
860.00	Mortgage Loan		860.00
29 900.00	Commonwealth Treasury Bonds & Inscribed Stock (at cost)		29 900.00
7 000.00	Interest Bearing Deposits		7 000.00
15 000.00	Library (at valuation for insurance)		15 000.00
16 157.50	Publications (at selling price)		16 389.60
$88 377.18			$88 313.02

The Society owns works of art which have been donated over the years and which do not appear on the Balance Sheet. They are all housed in the Tasmanian Museum and Art Gallery and are covered by that organisation's insurance. A catalogue is available to members listing these works of art.

T.A.H. Knight
Honorary Treasurer

A HISTORY OF THE TASMANIAN SCALLOP INDUSTRY: DIAGNOSING PROBLEMS OF MANAGEMENT

by R.A. Perrin and P.R. Hay

(with one table)

PERRIN, R.A. & HAY, P.R., 1987 (30:vi): A history of the Tasmanian scallop industry: diagnosing problems of management. *Pap. Proc. R. Soc. Tasm.*, 121: 1-14. ISSN 0080-4703. Centre for Environmental Studies, University of Tasmania, Hobart, Australia 7000.

Three distinct phases occur in the history of management of the Tasmanian scallop industry, corresponding with a shift in the industry's locus, from D'Entrecasteaux Channel to the East Coast, and thence to Bass Strait. Each shift was prompted by crisis in the industry, and though the result on each occasion was to dramatically increase the scale of the industry, the record has been one of *ad hoc* implementation of ultimately ineffective strategies. Though there are some local factors accounting for this, most are deep-seated and resistant to easy resolution — they have to do with the biology of the scallop, with its status as a common property resource, and with the ongoing failure to develop theoretical models of fisheries management appropriate to the scallop industry. It seems unlikely that the industry's management problems can be easily and quickly solved.

Key Words: scallop industry, Tasmania, management.

INTRODUCTION

Beginning as a weekend leisure activity for a few enterprising Hobart citizens at the turn of the century, scallop fishing has developed into a major, highly-capitalised industry. It is an industry which has been the subject of many controversies in its comparatively short history, and these have both stemmed from and been fueled by periodic collapses of production in the industry. That these collapses continue to occur suggests one or both of the following: a poor management record and/or chronic problems stemming from the biological and resource nature of the scallop. We believe the latter to be more significant. Though some lack of political will to come to terms with the problems is evident, the obstacles to sound management are nevertheless formidable, and defy easy resolution. It is thus unreasonable to expect too much progress too soon.

In the account which follows, three distinct periods are identified, each corresponding with industry expansion as focus shifted from depleted to major new beds.

TO 1950'S: INDUSTRY BASED ON THE D'ENTRECASTEAUX CHANNEL

Europeans did not exploit scallops in a significant way until the early 1900's. A Royal Commission into the fisheries of Tasmania in 1883 deemed the only shellfish worthy of special notice to be oysters and mussels (Seal *et al.* 1883). The Commission noted the consumption of scallops in the vicinity of the coast, but reported that scallops did not find their way to the Hobart market. One petitioner to the Commission stated that only oysters seemed to be considered of value and in demand and that the poor of Tasmania did not avail themselves of the possibilities of employment in an industry which in England and elsewhere provided employment for thousands. There was evidence even at this stage of over-exploitation of fishing resources, for oysters, once plentiful around the coastline, now existed in commercial quantities only in the vicinity of Spring Bay (*loc. cit.*). The need for management of the ocean fisheries was clearly recognised, and the Commissioners saw historical developments in other fishing industries, and research into the natural history of fish species as two important considerations in the formulation of a fisheries management policy.

Until this time, Tasmania's fisheries had been managed by the Salmon Commissioners (see table 1), appointed in 1861 (Henry 1861), and mostly involved with the stocking of Tasmanian rivers with salmon or trout via the importation and breeding of salmon and trout eggs (Innes 1865). In 1884 however, in response to the 1883 Royal Commission findings, Mr W. Saville-Kent was

appointed Superintendent and Inspector of a newly created Fisheries Department (table 1). Although Saville-Kent (1886) was concerned mostly with the problems of the oyster fishery he did comment on the general state of the Tasmanian sea fisheries and suggested that investment in the fishing industry would be worthwhile with "the adoption of newer methods and a more extended and systematic plan of working the fisheries and disposing of their produce." Thus even at this time there was an awareness of the need for management in the development of the fishing industry.

Although no significant market existed for scallops in the nineteenth century, in the early parts of the twentieth century scalloping was undertaken from rowing or sailing boats and by using small dredges in the vicinity of the Marine Board Shipyards and Rose Bay (Fairbridge 1953) and as far north as New Town Bay (E. Guiler, pers. comm.). Both the commercial scallop *Pecten fumata* Tate and the doughboy scallop *Chlamys asperrimus* Lamarck were being caught. It seems that the only other species of scallop found in Tasmania, the queen scallop *Equichlamys bifrons* Lamarck was less common than the other two species, and was not mentioned in the earlier reports referred to above. By 1905 internal combustion marine engines had been introduced and the major technological impediment to full-scale exploitation of the scallop resource was removed. Though existing scallop beds around Hobart had begun to dwindle, dredging could now move to the entrance of the Derwent River, Ralphs Bay and the Channel. The young industry was quite buoyant and sufficient quantities were being taken to satisfy demand, mostly from hotels which provided free scallop counter lunches.

Until 1893 the Commissioners of Fisheries were supported by an annual parliamentary vote, but after that year they derived their salaries and running costs from the taking of fees levied on fishermen (Seager 1908). Apparent over-exploitation of the known scallop beds was already taking place. The decline in the number of scallops in the vicinity of Hobart led the Commissioner of Fisheries, Mr P. Seager, to impose in 1908 the first closure, when scalloping in the Derwent was discontinued "to allow the beds to recuperate" (Seager 1908). The Commissioner was petitioned by the scallop fishermen on more than one occasion to re-open the scallop beds; instead he appointed a two-man committee to test the recovery or otherwise of the bed (Seager 1910). The committee made eleven dredge hauls over the Derwent River beds and found virtually no young scallops growing on the western side of the Derwent, though there was a reasonable growth elsewhere. Factors thought to be contributing to the poor growth of scallops were an increase in the number of *Auricula* sp. (a parasitic protozoan), the increasing silt load in the river, the discharge of sewage and an increase in algal growth. The committee recommended the reopening of the beds to scalloping on the grounds "that a thorough cleaning of these beds might effect an improvement" (*The Mercury* 8 July 1910). The Commissioner of Fisheries demurred — he did not consider the committee's findings justified its conclusions and he declined to remove the restrictions, but the committee was authorised to make further investigations (Seager 1910). In 1912 it was decided on the recommendation of the committee to reopen the Derwent to scalloping, with the following restrictions; that scallops could be taken by dredges towed by boats propelled by oars only, and the person taking the scallops was to pay a licence fee of five shillings for each dredge used (Seager 1912). When these restrictions were lifted is unclear.

The scallop fishery was not mentioned in a second Royal Commission on Tasmanian Fisheries in 1916, indicating that the fishery was still operating only on a small scale. The Royal Commission inquired into the causes of the high price of fish on the local market and was critical of the way most fisheries were unexploited in Tasmania, stating that "no island state has ever yet reached full development without the thorough exploitation of its fishing resources" (Flynn 1916), an assessment hardly justified in the case of scallops which by this time had all but disappeared from the major field — the Hobart area of the Derwent. In 1918 the Commissioner of Fisheries appointed a further committee, headed by T. Thompson Flynn, Ralston Professor of Biology at the University of Tasmania, to continue investigations into the reduction in scallop numbers in the Derwent River. Intensive dredging over the scallop beds, produced "as many full-sized scallops as could be counted on the fingers of both hands" (Flynn 1918). In Flynn's first report he suggested four possible causes of the decline in the scallop population: increased silt and mud load in the river, increased numbers of parasites, increased numbers of starfish, and fluctuations in the water salinity. In his second and final report he found that the Derwent was again stocked with young scallops and concluded that their previous disappearance had been caused by unusual flooding, resulting in an increase in silt load in the Derwent and drastic fluctuation in the water salinity (Flynn 1919).

The Commissioner of Fisheries' report for the year 1918-19 stated that "the industry of

TABLE 1

Evolution of Tasmanian fisheries management structure.

Management Authority	Year	Legislation	Comments
Salmon and Freshwater Fisheries Commission	1861	Government Notice 148 — 21 October 1861	A 6 member commission set up to oversee the importation of salmon ova from England.
Superintendent and Inspector of Fisheries*	1884	Fisheries	Mr W. Saville-Kent was appointed as a result of the 1882 Royal Commission on the Fisheries of Tasmania.
Fisheries Board	1887	Government Notice 321 — 8 November 1887	A 23 member Board appointed partly as a result of Mr Saville-Kent's recommendation.
Commissioners of Fisheries	1889	Fisheries Act, 1889	25 people were appointed as Commissioners of Fisheries on 16 December, 1889.
Sea Fisheries Board	1925	Fisheries Act, 1925	The Commissioners of Fisheries were split, in 1925, into the Salmon and Freshwater Fisheries Commission and the Sea Fisheries Board which comprised 4 members.
Fisheries Division, Department of Agriculture	1941	Fisheries Act, 1935	The Division was supervised by the Department of Agriculture and headed by Mr R. Scott.
Fisheries Division, Department of Agriculture and the Tasmanian Fisheries Development Authority (T.F.D.A.)	1977	Fisheries Development Act, 1977	The T.F.D.A. was established on the recommendation of the O'Kelly Report, commissioned in 1976.
Department of Sea Fisheries	1985	Fisheries Development Repeal Act, 1985 Fisheries Amendment Act, 1985	A second review by O'Kelly in 1984 recommended the disbanding of the T.F.D.A. and reforming a Sea Fisheries Department.

* From 1884-1941 the management authority was known as the "Fisheries Department" an appellation which disguises the significant changes (including nomenclature changes) outlined above.

scalloping has now assumed such importance to the people that it must be developed and protected" (Seager 1919). Despite this recognition however, no new management initiatives seem to have been set in place. Again the focus of scalloping began to shift, from Ralphs Bay and the mouth of the Derwent, to the northern half of D'Entrecasteaux Channel. The industry expanded slowly. In 1920 only two scallop boats were engaged full-time in the trade; in 1924 several boats were scalloping. The increased pressure on the scallop stocks resulted in a number of management decisions aimed at protecting the stock. A season of six months, from April to September, and minimum sizes of three and a half inches (85 mm) for the commercial scallop and two and a half inches (63.5 mm) for the doughboy scallop, were imposed (Brown 1960). This virtually ended scalloping in the Derwent River and Ralphs Bay and increased the effort in the northern parts of D'Entrecasteaux Channel and in Northwest Bay.

In 1925 the government replaced the Commissioner of Fisheries with the four member Sea Fisheries Board (table 1) with the professed aim of stimulating development in marine fishing (Ogilvie 1925). One of its first acts was to close the northern beds of the D'Entrecasteaux Channel, apparently to prevent over-fishing (Fairbridge 1953, Brown 1960). It is hard to assess the accuracy of the over-fishing claim at this time as there were no annual reports to parliament by the Sea Fisheries Board from 1925 until 1941; available data consist only of the 1929 to 1939 total scallop catch figures, which were collected verbally by the Inspector of Fisheries. These demonstrated the comparatively small scale of the industry at the beginning of this period, though steady and impressive growth occurred after 1933 (Harrison 1965). The species-basis of the

industry was also changing. Until 1932 larger numbers of commercial scallops were taken; after this time doughboy scallops were taken in greater numbers. Harrison 1965) suggested that the manifest economic advantages of commercial over doughboy scallops can only mean that the commercial scallop was quite rare in the D'Entrecasteaux Channel during the 1930's.

As well as closure in 1925 of the Channel for two years, other management measures were taken in the interests of conserving the resource. In 1928 the scallop season was reduced by two months, whilst the Channel beds were re-opened for fishing, only to be closed again in 1930 and 1931. The minimum legal size of the commercial scallop was changed by the Sea Fisheries Board in 1934 from three and a half inches (85 mm) at its largest diameter to three and a half inches at its smallest diameter. In 1935 dredges were limited to a width of four feet (1.2 m) to protect the scallops from being crushed by the weight of the net being dragged over the bottom. From 1938 until 1942 there were fluctuations in the total catch of scallops due to petrol and manpower shortages during World War II: however meat rationing increased the demand for scallops and resulted in stepped-up fishing effort, facilitated by the extension of the scallop season by two weeks.

An important change in industry management at this time was the transfer, in June 1941, of the functions and responsibilities of the Sea Fisheries Board to the Minister for Agriculture (table 1). An Advisory Board was constituted, consisting of the Secretary for Agriculture, Secretary of the Police Department, a zoologist, a fish processor, and two fishermen representing the south and east coasts (Smith 1942). Annual reports of the Board were published as part of the Agriculture Department's reports.

The Channel scallop industry continued to increase production through the 1940's, but in 1949 catches decreased markedly, indicating that almost fifty years into its history, little progress had been made in effective regulation of the resource. From the foregoing it will be apparent that little consistency or sophistication characterised attempts to manage the resource in this early phase. Though the means adopted — restrictions on permissible technique, limitations, via licence, on open access to the resource, and temporary bed closure — remain the major regulatory tools to the present, little progress was made toward understanding the nature of the resource or monitoring population changes. Assessment was not continuous but occurred only when serious drops in the scallop population had become obvious. Subsequent restrictions were thus never in time to protect the industry in the short term, though sufficient to permit recovery in the intermediate term.

1950'S-1973: INDUSTRY BASED ON THE EAST COAST BEDS

The poor catches of the late 1940's continued into the early 1950's. A.M. Olsen, Senior Research Officer with the CSIRO Division of Fisheries, carried out research in the 1950's aimed at explaining the decline in Channel scallop numbers. He found the minimum concentration of scallops for economic fishing to be two per square yard (approx. one square metre) and established that the scallops were preyed upon by the large whelk or band shell *Fasciolaria australasia* Perry and by the eleven-armed starfish *Coscinasterias calamaria* Gray. Olsen (1955) contended that concern expressed about the reduction in scallop numbers in the D'Entrecasteaux Channel may have been misguided:

> It is well recognized that fishing never exterminates a stock but reduces the stock to individuals of minimum legal size and/or an uneconomic level of operation. Therefore so long as there is an ample breeding stock of those below the minimum legal size, any proposal restricting areas of dredging is preventing the rational exploitation of a fishable stock.

Olsen's controversial position set one of the boundaries to the appropriate management response to population shortfall debate which continues to this day.

Despite the attention still being acccorded the Channel, it was shortly to be eclipsed as Tasmania's prime bed. Increasingly the industry began to explore and exploit beds on the east coast of Tasmania, and the late 1950's was a period of industry expansion.

In 1960 a Select Committee of the Legislative Council was appointed to inquire into the scallop fishery. The enquiry was initiated by the controversy surrounding the introduction of a new spike-toothed dredge, the "sputnik" dredge. Apparent damage to the scallop beds prompted submissions from 45 fishermen, an indication of considerable concern. Other issues raised by the fishermen included perceived inadequate management by the Fisheries Division, and in particular the lack of research into scallop behaviour and that of its major predator, the starfish (Prince *et al.* 1960). This constitutes the first clear evidence of a rift between regulator and client. It reflects the inherent

and persistent difficulties of scallop management alluded to earlier: one would expect these to lead to friction and impatience between industry and management, and the wonder of it rather is that clear evidence of this dissatisfaction has not been found in earlier periods. It may also be a measure of the greatly increased professionalisation and technological sophistication of the industry from the 1950's.

The select Committee brought down an Interim Report which made a number of management recommendations. Many of these aimed at overcoming research and monitoring deficiencies characteristic of the industry hitherto. These included the appointment, for the first time, of research staff specifically to investigate scallops (or, more accurately, to give scallop research priority amongst other research tasks), and investigation of the scallop beds. Nevertheless, most recommendations involved expansion and sophistication of existing techniques aimed at guaranteeing the resource against over-exploitation: increasing the number of fisheries inspectors, increasing fines for breaches of fisheries regulations, registering sheds where scallops were split, shortening the scallop season by two weeks, prohibiting night fishing, restricting the issue of scallop licenses, reintroducing separate licences for scallop fishing (including special endorsements for the Channel area and Norfolk Bay beds), taking a substantial fee to provide a worthwhile contribution to the administration of the Sea Fisheries Board, and undertaking a program to control starfish numbers (Brown 1960). The emphasis in the above recommendations on tightening the Board's policing effectiveness highlights the Select Committee's belief that a major reason for earlier management failure was incapacity to enforce adequately the measures taken, rather than inappropriateness of the measures themselves.

After research into the effects of different types of dredges on scallop beds the Committee submitted a second report in 1961 which recommended that the lip dredge and lip dredge with runners be permitted; that restrictions on dredge type only apply to the D'Entrecasteaux Channel; that a fisherman education program begin; and that Tasmanian scallop processors market their scallops so that they be clearly and attractively identified as Tasmanian (Brown 1961). Little good seems to have come from these recommendations; the lip dredge with runners proved unsuccessful, no effective program aimed at fisherman education was set up, and there was no apparent increase in marketing Tasmanian scallops as Tasmanian.

The success of the more important recommendations in the Interim Report was also mixed. Research into scallop dredge design was undertaken, night fishing was prohibited in the Channel, a temporary reduction of the season was instituted, and scallop sheds were registered with the Department of Health. Other recommendations were either not adopted or proved ineffective. For instance, there was no restriction on the issue of scallop licences, and no substantial fee was taken to contribute to the administration of the Board, whilst an increase in fines for breaches of fisheries regulations was instituted, but to no good effect, as magistrates tended habitually to impose only the minimum fine.

The disappointing fate of the Select Committee's recommendations reflects the management difficulties posed by scallop utilization, and the mix of incapacity and unwillingness to tackle with determination these difficulties on the part of management. It lends credence to the feelings of some fishermen that the government lacked the will to apply the recommendations stemming from the Select Committee enquiry. The Channel scallop beds were partly closed again in 1964 as a result of over-fishing, and incentives were thereafter given to fishermen by the Sea Fisheries Advisory Board to locate new scallop beds to maintain the fishery. The incentives took the form of temporary exclusive rights of access to a newly discovered scallop bed. By the late 1960's the east coast beds were also becoming severely depleted, further highlighting the failure of the State's management strategy. The late 1960's were years of low spatfall, and at this time Tasmania had to confront serious interstate competition for the first time. Although Victoria's scallop industry only came into being in the early 1960's (as a result of exploration by Tasmanian fishermen), by 1970 it had supplanted Tasmania as Australia's leading scallop producer (Sanders 1970). The constitutional problems the industry experiences today date from this time.

Yet again the industry was in a state of crisis, and in danger of collapsing under the twin weights of years of poor recruitment and vigorous interstate competition. Again crisis forced the industry into a new phase, as management responded in the same way as it had done in the 1950's; it launched a campaign to discover exploitable new beds. Much of the initiative to find new scallop beds was undertaken by the Sea Fisheries Division of the Department of Agriculture, which surveyed 800 square miles (approx. 200,000 hectares) of Bass Strait for scallop beds in 1972. This search revealed four areas with high densities. The depletion of the

scallop stocks in the Derwent River and Ralphs Bay, the Channel and finally the east coast led the Minister for Agriculture, Mr L. Costello, to release policy statement regarding the likely exploitation of the Bass Strait scallop beds. According to Mr Costello "a slower rate of exploitation by smaller, lighter dredges was considered to be more desirable than an uncontrolled quick decimation of the stock" (*The Mercury* 6 June 1973). A determination not to re-commit the errors of the past seemed evident. Nevertheless, occasionally remnants of old ways of thinking remained in evidence, such as Mr Costello's threat on 13 June 1973 that unless local interest in the newly opened Bass Strait beds quickened, he would throw those beds open to Victorian fishermen, as "he was not prepared to see a valuable food resource 'wasted'" (*The Mercury* 14 June 1973). Such a statement reads almost incredibly in light of current interstate tension over exploitation of what has, in turn, proven a finite fishing resource, and leads one to question how deeply embedded, in 1973, was the apparent new-found determination to husband the resource wisely and to adopt a more responsible approach to management.

1973-PRESENT: INDUSTRY BASED ON BASS STRAIT BEDS

This period has seen not only a shift in the geographical locus of the industry — it is also characterized by a greatly stepped-up research emphasis, at least by comparison with the industry's earlier phases. Since 1973, for instance, the Sea Fisheries Division of the Department of Agriculture has been conducting biological studies into the life history of the scallop with the aim of assessing the potential for scallop aquaculture, which would involve the growing of young scallops artificially and then releasing them into depleted natural areas (Dix 1975).

In 1976 the Tasmanian government commissioned a report on the fishing industry by the Chairman of the Irish Sea Fisheries Board, Mr B. H. O'Kelly. That report found that further development was hindered by the "existing administrative structure", in that the Fisheries Division, a small group within the Department of Agriculture, could not manage effectively because of the need to live with wider departmental priorities, and other problems relating to the inertia and unwieldiness often characteristic of large bureaucracies. O'Kelly recommended the establishment of a Sea Fisheries Development Authority charged with specific responsibility for the development of the industry. The government endorsed the report and established the Authority under the Fisheries Development Act which came into effect in September 1977 (table 1). Though the Sea Fisheries Division remained, the Tasmanian Fisheries Development Authority (TFDA), consisting of a chairman (the manager of the Agricultural Bank of Tasmania) and four other government appointees, commenced operation later that year, with three aims: to promote and develop the fishing industry; to maintain standards of exports and local products; and to research the management of living resources (Shoobridge 1979). One of the Authority's first acts was to expand the earlier work on scallop aquaculture.

Scallop fishing in Bass Strait introduced a new set of management problems. Questions of Federal-State jurisdiction over coastal waters became apparent in the 1970's and remained long unresolved. Until June 1986, Tasmanian authorities had control over the waters up to 3 nautical miles (approx. 5.6 km) from the coastline, while the Federal authorities controlled the 3 to 200 nautical mile Exclusive Fishing Zone. This led to competition between Victorian and Tasmanian scallop boats with the potential result of over-fishing and economic hardship for some scallopers, and a possible spillover of excess fishermen into other fisheries such as the crayfish and shark fisheries. In 1979 Tasmanian fishermen took their concern to government and the then Minister for Sea Fisheries, Dr J. Amos, called for a division of Bass Strait along the 39° 12'S parallel, a simple enough claim which gives no hint of the formidable constitutional and political difficulties standing in the way of such a course of action. Predictably, no action ensued at that time and subsequent slow progress toward reaching the Off-shore Constitutional Settlement highlights these difficulties. Lack of progress toward putting the Settlement in place was locally ascribed to intransigence on the part of the Victorian Government, which was reluctant to have its industry's access to Tasmanian waters removed, this being the effect of a related but separately wrought agreement whereby exclusive rights to fish to 20 nautical miles (approx. 37 km) from the coast devolve to Tasmania.

The controversy surrounding the management of the scallop beds resulted, in November 1983, in a joint Commonwealth-Victorian-Tasmanian moratorium on the issue of scallop licences to fish in Bass Strait until the end of 1984 (the "interim Management Regime"), to give the Commonwealth time to evaluate a comprehensive long-term management plan for this area. The

moratorium was designed to limit the entry of boats to the Bass Strait fishery as a means of controlling the build-up of fishing capacity. Eligibility for a licence was based on a demonstrated commitment to the fishery which could be shown in a number of ways, such as by proving that a boat had fished in the area during the previous season, by having commenced to build a boat for scalloping, or by holding a licence to fish for scallops in the coastal waters of Victoria. A second major intergovernmental initiative for the Bass Strait scallop fishery, the Bass Strait Scallop Fishery Task Force, consisting of officials from the Commonwealth, Tasmanian and Victorian fisheries authorities and from the industry, was established in June 1984 to prepare a report on options for future management of the fishery for consideration by the relevant governments. In July 1985 the relevant State and Commonwealth Ministers announced details of a new management regime, involving the phased handing over of responsibility for the fishery to Victoria and Tasmania (after each State had provided a management plan for its zone). This was enabled by the decision of the Commonwealth to implement the Fisheries component of the Offshore Constitutional Settlement, and means that the fishery can eventually be controlled under a single law. Under the scheme, three fisheries were created — one controlled by each of the States to 20 nautical miles offshore, and a third under joint Tasmanian-Victorian control. After much delay this came into effect in June 1986.

Of recent years there has been some recovery in Tasmania's depleted beds. The D'Entrecasteaux Channel scallop fishery was again opened, after 15 years closure, to commercial and amateur fishermen in 1982. Severe restrictions were imposed. Commercial scallops could not be taken at all after the 1983 season, bag limits were introduced, and the scalloping season was set at three weeks. There was, however, no restriction on the numbers of boats allowed to fish and in 1983, 666 recreational boats and 70 commercial boats were working the beds. In 1984 the daily bag limit for amateurs was reduced from one bag containing up to 1000 scallops to one bag containing 400 scallops and for professional fishermen from 15 bags containing a total of 15000 scallops to 20 bags containing a total of 8000 scallops.

Changes also continue to occur in the structure of industry management. In February 1985 the TFDA and Sea Fisheries Division became incorporated in the Department of Sea Fisheries (table 1) whilst the Fisheries inspectors were incorporated into the Police Force. There are also indications that the research effort of the last decade is starting to yield results. It was announced, for instance (*The Mercury* 25 January 1986), that the Department of Sea Fisheries had achieved a "major breakthrough" in the "re-establishment of over-fished scallop beds", involving "the transplanting of scallops from controlled breeding grounds to the seabed", a process whereby scallops are able to reach legal size "in as little as 17 months" instead of the normal two to three years.

That management continued to find resolution of the industry's long-standing problems difficult however, is evinced by the media-grabbing turmoil which reigned in the industry through 1985. At one stage violent clashes between Victorian and Tasmanian fishermen seemed imminent, and there was talk of new beds being fished out within days of discovery, of excessive catches going to rot, of splits in the ranks of the Tasmanian Scallop Fishermen's Association, and a general increase in fishermen militancy. *The Mercury* was in no doubt about the continued failure of management to regulate the industry effectively. It editorialised (21 October 1985): "Every time a new bed is discovered, it is virtually fished to exhaustion as fishermen flock in to reap a benefit from a bonanza they know from past experience will have a limited life."

LESSONS FROM HISTORY

From a management perspective, the most striking aspect of this history is that, from its beginnings to the present, problems and management responses have remained little changed — though considerable experimentation with administrative structures and arrangement has taken place. The industry's major beds have been subject to spectacular and largely unpredicted falls in population, and no mechanisms has been found to control fishing effort in such a way as to stabilize the industry both ecologically and economically. In the past crises have been averted by the discovery and opening up of new beds, but this option is probably no longer available in any major sense, whilst the increase in fishing capacity in the wake of significant technological innovations since the 1950's now provides the means to overfish such new beds as are located in an extremely short period of time. Pressure on management has thus increased commensurate with fishing capacity.

It is beyond the scope of this paper to prescribe management solutions. This has become a major government priority, and it is also the focus of academic investigation elsewhere. We intend merely to account for the management record

outlined above. Some of the difficulties can be attributed to inadequate resources and a lack of political will on the part of the authorities. Instances of this can be intelligently guessed at from the account given above. But it is also necessary to identify the chronic and possibly greater difficulties which are inherent in scallop management. To these we now turn.

FACTORS CONDUCIVE TO MANAGEMENT FAILURE

Scallop Biology

The problems posed by the biological nature of the resource have been well identified elsewhere (Harrison 1965, 1975, St Leger 1964, Dix 1981, Hortle 1983) and will be only briefly surveyed here. They are, however, formidable. Harrison (1975) has noted the "apparent sensitivity of the recruitment process to environmental conditions", whereby "we have a population behaviour pattern perhaps more akin to that of plague insects such as locusts than fish". Annual fluctuation in the spatfall success rate of all species of Tasmanian scallop is enormous. This is not peculiar to Tasmania — it has been reported from nearly all scallop fisheries, both in Australia and elsewhere. The causes of these fluctuations are still unknown, but their importance to the health of the fishery is undoubted. The number of larvae settling in one year will determine the availability of stock for the fishery in approximately three years time. Fishermen who exploit an area of scallop beds in one year are not necessarily guaranteed a sucessful consecutive year owing to this variability of spatfall. This factor may underlie the major collapses which have occurred in the scallop fishery since exploitation began. Thus an accurate assessment of the spatfall success is crucial to good management procedures. In addition, little is thus far known of the scallop's susceptibility to disease.

The Failure of Theoretical Models

As with other fishing industries, scallop management suffers from the failure to develop the appropriate theoretical models to obviate the necessity of reinventing the wheel every time a management strategy must be devised. There are three competing paradigms of fishery exploitation: Maximum Sustainable Yield (MSY), Maximum Economic Yield (MEY), and Optimum Sustainable Yield (OSY). We contend that all have proven of limited practical use.

The MSY concept has underwritten most fishing management policies in the past fifty years or so (Larkin 1977). It first arose as a management concept in the early twentieth century in the Norwegian whaling industry. Using information they had collected on fin and blue whales from the Antarctic and off the Icelandic coast, the Norwegians discussed the relationship between regeneration and catch of whales in the hope of finding a mathematical model to help them establish the minimum stock of whales which could yield a given catch without exterminating the stock. They found that in the case of whales the data base was not sufficient to afford an adequate foundation for a calculation: however they did suggest that there is a definite level to which the whale stock can be reduced, while preserving the maximum capacity of regeneration and at the same time securing an optimum catch. Others (Ricker 1948, 1958, Fry 1947, Schaefer 1954, Beverton & Holt 1957) further refined the concept, and it became the standard strategy for fisheries management, in Australia, as elsewhere. Larkin (1977) provides a jaundiced definition: "any species each year produces a harvestable surplus, and if you take that much, and no more, you can go on getting it for ever and ever".

The theoretical validity of MSY has been demonstrated under laboratory conditions, but attempts to use MSY as the sole management tool in the field have met with severe problems, leading one fisheries scientist to state that "the generalised concept of MSY is elegant in both its simplicity and its adherence to the basic theories of the behaviour of the population. The problem is that as applied it is totally unsound." (Talbot 1978).

What then are the major problems confronting the fisheries manager who attempts to use MSY as the major management objective? The most fundamental problem is the difficulty of observing and accurately measuring the relevant dynamics of any living marine resource. This is due in part to the technical problems of data collection in the marine environment but also to the heavy costs associated with sampling and processing data. The most extensive sampling programme of the fishing resource is undertaken by the fishermen themselves; however their figures are never completely free of reporting biases, for the fishermen have an economic disincentive to divulge such fishing catch data as locality and abundance of fish stocks for fear of advantaging their fishing competitors, whilst there is also in many cases a lack of scientific method and accuracy in recording results. In the Tasmanian scallop industry estimates of scallop numbers are made by making a number of dredge

hauls over known scallop beds (Zacharin 1985). This system allows an estimate of the capabilities of the beds to support a fishery in any given year but because of the extremely variable recruitment of the scallop, it would only provide a tenuous basis for an MSY prediction.

A second problem concerns the failure of the MSY concept to deal with multispecies fisheries, as it was derived to predict the yield of one species or race only. For example, in the Pacific Northwest salmon fishery it has been found that the salmon population consists of races with different growth rates, recruitment, and mortality, and thus, different yield functions. They can however be caught together in the one net. An MSY estimate in this case ideally should be made for each race (Ricker 1973). The Tasmanian scallop fishery sometimes involves the dredging of more than one species of scallop as well as an assortment of other species of fish, invertebrates and algae. At present these other species have no commercial value (it is possible that some of them may eventully be utilized as food sources, or as fertilizer), though their value to the marine ecosystem, as yet unknown, could be considerable. The harvesting of trophically linked species can also drastically reduce the MSY for a living resource. In the case of the scallop, which is a plankton feeder, no apparent problem exists as plankton is not harvested in Tasmania. For a scallop management regime to be successfully implemented, there should be a calculation of the MSY for each species/race being fished. This would lead to much effort and expense for the fisheries authorities and also to frustration for fishermen who would have to sort, count and itemise their catch.

For most species of fish, the critical age for harvesting is close to the first age of maturity when growth in weight is rapid and natural mortality is low. Scallops are no exception to this general rule (Gwyther et al. 1984). Thus the reproductive portion of an exploited population would normally be made up of young adults. In the event of a natural catastrophe (such as unseasonally warm or cold water) which killed most fish, the ability of the population to recover is impaired by the lack of mature fish. As scallops are known to have dramatic fluctuations in their annual numbers an MSY prediction could only be made at best on a year to year basis and the dangers associated with an overestimation would be acute.

Although MSY contains these inadequacies it would be unwise to discard the concept entirely. If there is a demand from society for the utilization and conservation of a resource then MSY would appear to form the upper limit of exploitation which would ensure the survival of the species against excessive fishing mortality. This all makes sense in a strictly biological framework, but fisheries managers must contend with more than just biological factors. In particular they must also consider the welfare of the industry participants. Other management concepts have been embraced in recent times which have resulted in a shift from management along strictly biological lines towards the economic management of fisheries. Hence the development of Maximum Economic Yield, a concept which modifies the biologists' MSY model to derive a cost/revenue curve by transposing yield to its revenue equivalent. By highlighting the low return for effort involved at the margins of MSY, MEY tends — in theory — to establish exploitation levels at a lower total fishing effort than MSY, and might therefore be expected to provide greater protection of the resource from the dangers of overfishing.

Again, however, there are problems which limit its practical applicability. The first problem, and one which is particularly relevant to the Tasmanian scallop fishery, arises from the competing interests of commercial and recreational fishermen. Commercial fishermen usually wish to exploit a resource to maximize their profits while recreational fisherman normally attempt to maximize their pleasure, of which only a portion may be financial return. The commercial fishermen's aims are not contradicted by the concept of MEY when their combined total effort can be controlled; but pleasure for recreational fishermen may mean such intangibles as the escape from suburbanism, aesthetic value of fishing, or hunting instinct release, which will not translate into a computation of MEY. This quandary faces the fisheries managers in the Tasmanian scallop fishery, and an MEY concept in this context would have little value in helping to formulate a joint recreational/commercial fishery management plan.

The second problem with managing a fishery along MEY lines stems from the common property nature of the fishing resource, to be discussed below. Fishermen, like other businessmen, seek to maximize their profits. In a situation where there are no external controls on the number of boats, capital will pour into the industry while fishermen perceive the chance of profits until the profit margin finally dissipates. The late entrants into a fishery will sink capital which, because of reduced stocks and increased total fishing effort, will result in the fishery becoming over-capitalised. Thus in an unregulated fishery the MEY inevitably will be

surpassed, leading to a need for external intervention to reduce fishing effort. In the Bass Strait scallop fishery there has been a limit on the number of licences issued to fish for scallops, though catch quotas appear to be the favoured option for the fishery's long-term management (B. Lilburn, Chairman, Bass Strait Scallop Fishery Task Force, pers. comm.). This restriction of effort, while having the admirable aim of protecting the resource and increasing profits for participants, is plagued by distributional inequities. The problem of who should get a licence, for instance, is a most vexing one, and fraught with political and ethical problems.

Thirdly, MEY can only be accurately plotted if the price remains constant. But the price of Tasmanian scallops varies within the State and in other States, depending on demand and supply at different times of the year and on the variable costs associated with the different markets to which they are sent. The assumption that fishing vessels, their catch effectiveness and their operating costs are roughly comparable is also invalid, for fishing is undertaken by a variety of sizes of boats with varying operating costs and catch effectiveness. In addition, as with MSY the data base required to make an assessment of MEY for the Tasmanian scallop fishery would be extremely difficult to obtain, due, again, to the reluctance of some fisherman to divulge the information, the need to update constantly cost and price data, and the costs of gathering and processing the information. An accurate assessment of MEY is thus unlikely.

Finally the effects of improvements in fishing technology on the level of effort and economic efficiency further upset any attempts to manage a fishery in accordance with MEY. In a situation where technological improvements are unregulated, fishing effort can rapidly escalate beyond the MEY; however, where they are regulated, account must be made of the economic inefficiencies created by such a policy and the associated problems (Whitmarsh 1983). In the scallop fishery there have been a number of technological innovations such as changes in dredge size and efficiency, improvements in boat performance, and the recent introduction of scallop sorting machines to reduce handling time for fishermen. This last innovation has been examined carefully by the Bass Strait Scallop Fishery Task Force to assess its likely affect on scallop numbers. If it is too efficient, that is, if it creates the potential for rapid increases in fishing effort, its use will be restricted — an apposite example of regulated economic inefficiency which prevents a true MEY being taken.

With all these problems is there any value in attempting to manage a fishery on the basis of MEY? It would seem to be inappropriate for the Tasmanian scallop fishery in light of the above. However the MEY model does allow administrators to point out the dangers of excess effort and the importance of the problems posed by common property rights.

A third management paradigm is Optimum Sustainable Yield, a concept which arose from the 1958 Oceans Convention in Geneva (Stroud 1975). Unlike MSY and MEY it provides no models with which to structure practical data theoretically, and its flexibility has led to much criticism (Harville 1975). Who, for instance, is to define "optimum"? Croker (1975) argued that inevitably persons with the most political clout will be the final arbiters of what is optimal. Nor is there agreement about what OSY precisely is; it is usually defined vaguely in terms of MSY or MEY, with some social impact considerations like employment effects or regional social hardships tacked on. At the Australian Fisheries Conference held in Canberra in 1984 three issues were identified in the development of fisheries management plans. These were conservation of resources, economics of the industry and the social implications of any initiatives. If these three criteria are considered as the basis of an OSY programme, the OSY for scallop fisheries managers might be the fishing effort at which yield is below scallop recruitment level while still safely allowing a limited season for fishermen to work. In the latter requirement determination of the 'limited season' is obviously crucial. If the season is too long the problems outlined in the MSY and MEY sections will be encountered. If it is too short fisheries managers will be exposed to criticism for 'locking up' the resource. If restrictions were placed on the number of fishermen entering the fishery then some control on the fishing effort would be possible; however this will inevitably result in distributional inequities, as noted above. In addition, most commercial fishermen would probably interpret the OSY as being somewhat higher than the authority's interpretation, due to their capital outlay and desire to maximise their return on effort. OSY variables for recreational fishermen will differ again, for as we have seen, 'unquantifiables' such as the quality of derived pleasure are significant in their case.

It would thus seem that OSY is of limited applicability for the Tasmanian scallop fishery. In a wider sense OSY does attempt to fill the gaps left by the failure of MSY and MEY to address such problems as the sociological effects of management plans on, for example, employment and regional

hardships, but it clearly requires much greater refinement before it can be considered as an appropriate theoretical construct for the shaping of regulatory practice.

Common Property Rights

A number of other problems are endemic to management of the scallop industry. The constitutional and political difficulties involved in Bass Strait will not be easily solved and may periodically recur. Problems of technological advance are not only relevant to attempts to evaluate MEY: whatever management strategies are adopted the potential for innovation to inflict consequential damage upon the industry will remain a problem. There are also problems of political will. There will always be a tendency on the part of fishermen to maximize income in the short term and trust the long-term to look after itself (Berkes 1985). This will bring them into conflict with government and management, and in neither case can we assume that the will to resist fishermen's demands will necessarily exist. Politicians are susceptible to pressure from organized, articulate private interests. Administrators have a tendency to avoid the stress associated with an adversarial management relationship with clients by taking on the world view of those clients; a process known as 'clientism', whereby the steward of the public interest ceases to be such, and becomes instead the public sector facilitator of private interests.

How can we account for this divergence between public and private interest? The answer lies in the common property nature of many resources, including scallops. Here, too, much has already been written (Gordon 1954, Crutchfield & Pontecorvo 1969, Harrison 1975, Copes 1981, Welch 1983). It has long been recognized that the world's fishery crises stem from "the fact that these fisheries are common property resources to which fishermen generally have easy access. The fisheries are open to all who wish to exploit them and are owned by none" (Munro 1981). They tend to be recklessly used "because there are no private incentives to do otherwise" (Eagles 1984); "since fishermen do not own the fish until they have caught them, no individual fisherman can sensibly decide to refrain from fishing to allow the fish to grow and breed" (Victor 1979). Copes (1981) is even more explicit:

> "No one fisherman is personally motivated to conserve the resource, for any fish he would return to the water to grow to larger size will likely end up in the nets of a rival fisherman. Any expense he would undertake to conserve or enhance the fish stock, or to improve general fishery facilities, will yield him a negligible return. Most of the additions to the catch or improvements in returns that he would cause, will be enjoyed by other fishermen. When no individual is able to recoup an investment made in the fish stock, everyone will personally incline to neglect the future of the resource."

One influential observer has categorised this the "tragedy of the commons", to which he sees no technical solution, positing instead a moral solution (Hardin 1968) which has ben attacked in turn as politically fanciful and similarly incapable of constituting a solution (Crowe 1969). Hardin's "tragedy of the commons" has been applied to fishing and fish thus:

> "It is an important point of the Hardin paradigm that the decline comes about as the result of rational self-interest. Each new boat that a fisherman adds, brings him a gain of almost 1. But as the effecs of over-fishing will be shared by all, his loss will be only a fraction of 1. Thus as a rational decision-maker, the only sensible course for him is to add another boat." (Berkes 1985)

What is to be done? Many argue that the answer is to find ways of turning common property rights into some form of private right (cf. Welch 1983). In practice, as Harmon (1982) points out, once governments act to limit access to their fishing grounds, explicit or implicit property rights are established. A number of mechanisms for bestowing limited property rights which could protect the resource from over-exploitation exist. These could concentrate on industry outputs, in the form of a transferable quota system, whereby industry participants are allotted catch quotas which can be bought and sold. Tasmanian strategies, as with the rest of the world, have concentrated rather on input strategies. Hence the limited entry policy adopted for the time being at least, in the Bass Strait fishery. Sturgess *et al.* (1982) argue that any successful management strategy must be a modification of this, for although "relatively blunt", "fishermen have come to accept it and, presumably, base their expectations on it continuing", whereas "radical departures from this scheme, such as an output tax or annual output quotas for individuals may be resisted by fishermen". Crutchfield (1980) agrees: "a limited entry program can be phased in so that it minimizes the compulsion that must be exerted to trim the level of fishing to desired levels". There are difficulties however. As Meany (1980) and Sturgess & Meany (1982) point out, it will have little effect

unless coupled to restrictions on upgrading the fishing capacity of those granted entry. Possibly even more significant are "the profound social and political decisions" which must be made "in relation to the establishment of a limited entry fishery: to which individuals in the society is the exclusive fishing entitlement to be given?" (Dragun 1981–82). No entirely satisfactory system of allocating licences has been devised, and the further danger exists that, once allocated, the industry becomes a closed shop. At a still more general level it is unlikely, on ideological grounds, that there could be consensus on any extension of property rights beyond that conferred by limited entry. Many would agree with Lowry's (1971) call for an affirmation that the world's bodies of water and the resources within them, are inalienable public property.

Finally it has been suggested by Berkes (1985) that traditionally community-based constraints have successfully prevented over-fishing by utilizing a combination of territorial use rights and community moral sanctions to circumvent the "tragedy of the commons", and that herein lies the management solution to the future. Unfortunately, despite his sunny optimism, Berkes' evidence is curiously at odds with his argument: he notes the impossibility of such solutions in large-scale fisheries and that the impetus of technological change is antithetical to small-scale operations, and that in the market economy "economic relations tend to become free from the social framework" and hence beyond the control of informal community control mechanisms. Regrettably we must conclude that this seems an unpromising solution for the immediate and middle future.

SUMMARY

The history of Tasmania's scallop industry is one of recurring, unresolved problems, despite the periodic implementation of management initiatives. The factors contributing to this are complex and formidable: they are constitutional, political and bureaucratic, but they have still more to do with the biological and the common property natures of the resource, and with the failure to develop and apply satisfactory theoretical management models. Given that technological advances since the 1950's have greatly increased the industry's harvesting capacity, the need for effective management has been made much more acute. Political pressures can be expected to intensify as well, as entry into the industry becomes increasingly capital-intensive, and the financial consequences to individual fishermen of not having unrestrained access to the fishery are commensurately greater. Our conclusion is that management problems are likely to continue, largely for reasons which are endemic to the scallop's biology and resource-nature, and we should not unreasonably expect rapid progress towards resolution.

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(accepted 15 August 1986)

ISOLATED INTERMEDIATES — PRODUCTS OF LONG DISTANCE GENE DISPERSAL, PHANTOM HYBRIDITY OR CONVERGENT EVOLUTION? THE CASE OF THE HALF-BARKED *EUCALYPTUS AMYGDALINA*.

by J.B. Kirkpatrick and B.M. Potts

(with two tables and six text-figures)

KIRKPATRICK, J.B. & POTTS, B.M., 1987 (30:vi): Isolated intermediates — products of long distance gene dispersal, phantom hybridity or convergent evolution? The case of the half-barked *Eucalyptus amygdalina*. *Pap. Proc. R. Soc. Tasm.*, 121: 15-22. ISSN 0080-4703.Department of Geography and Department of Botany, University of Tasmania, Hobart, Tasmania.

Apparent intermediates between *Eucalyptus amygdalina* and *E. pulchella* occur well outside the recognized range of the latter species. Progenies of these isolated intermediates were grown in uniform conditions with progenies of trees of *E. pulchella*, *E. amygdalina* and apparent hybrids between these two species that are found where they occur parapatrically. The isolated intermediate population proved identical with *E. amygdalina* in seedling characteristics, while the parapatric intermediates were more variable than the other populations, this variability probably being partly the result of hybridization between *E. amygdalina* and either *E. tenuiramis* or *E. risdonii*. The allopatric intermediate population is more likely to have resulted from convergence of *E. amygdalina* in the direction of *E. pulchella* than from phantom hybridity or long distance gene migration.
Key Words: convergent evolution, *Eucalyptus*, gene dispersal, phantom hybrids.

INTRODUCTION

Species in the genus *Eucalyptus*, like many of those in *Quercus*, *Poa*, *Hieracium* and *Pinus*, tend to have blurred boundaries where they have parapatric distributions with their nearer relatives. Hybridization, intergradation and multidimensional clinal variation abound within the eucalypt subgenera (e.g. Pryor & Johnson 1971, Potts & Reid 1985a), bedevilling the taxonomist, but providing an excellent laboratory for biogeographic and evolutionary investigation (e.g. Barber 1955, Barber & Jackson 1957, Kirkpatrick *et al.* 1973, Moran & Hopper 1983, Potts & Reid 1985b). These patterns of variation may also provide evidence relevant to palaeoenvironmental reconstruction (e.g. Schlarbaum *et al.* 1982, Adams 1983), rarely exploited by the historical biogeographer and palaeontologist.

One of many patterns of spatial variation evident in *Eucalyptus* is a scattering of stands of individuals that are intermediate between one recognized species and another recognized species, within the range of only one of the recognized species (Pryor 1951, 1955, Pryor & Johnson, 1971, Ashton & Williams 1973, Parsons & Kirkpatrick 1972, Kirkpatrick *et al.* 1973, Kirkpatrick 1977a, Shaw *et al.* 1984). The most popular hypothesis to explain the existence of such stands is environmental change sufficient to eliminate one parent but not its hybrids with the other parent. This hypothesis has been established as reasonable in some cases (e.g. Kirkpatrick *et al.* 1973), but in other cases has faded under close examination (e.g. Kirkpatrick 1977a). One alternative to the phantom hybrid hypothesis is long distance dispersal by hybridization (Potts & Reid 1983, Potts & Jackson 1986). Pollen can travel further than eucalypt seeds, which are relatively heavy and have no apparent adaptations for long distance dispersal (Cunningham 1960, Kirkpatrick 1977b, Macphail 1979). The migration through hybridization hypothesis implies that the migrating species is locally expanding its range in response to environmental change (e.g. Potts 1986), whereas the phantom hybrid hypothesis implies local contraction. Thus, both hypotheses could be correct within the range of one species, and evidence independent of the phenetic and genetic characteristics of the isolated intermediate populations and their putative parents is usually needed to establish which is the more reasonable hypothesis for any one stand.

However, the phantom hybrid and migration through hybridization hypotheses do not constitute

all the options. Allopatric intermediate populations may represent ancestral cline forms linking both taxa or alternatively, characteristics of one species may have been independently selected from the gene pool of another species. In the case of such convergence it could be expected that not all characters of the plant would necessarily converge and that within-population and within-parent genetic variability would not be as high as could be the case in the initial phases of phantom hybridity and migration through hybridization.

There have been dramatic changes in environment in Tasmania in the last 17,000 years, it being only in the last 10,000 years that climatic patterns have approximated those of today (Macphail 1979). Glacial depositional evidence suggests that temperatures were 6° C-7° C colder in Tasmania at the height of the Last Glacial than at present (Kiernan 1983). Given this drop in temperature, a vast expansion of the area climatically incapable of supporting trees must have occurred between the onset and the peak of the Last Glacial, creating a large and long term barrier to the movement of species and their genes from the southeast of Tasmania to the north of Tasmania and *vice versa*

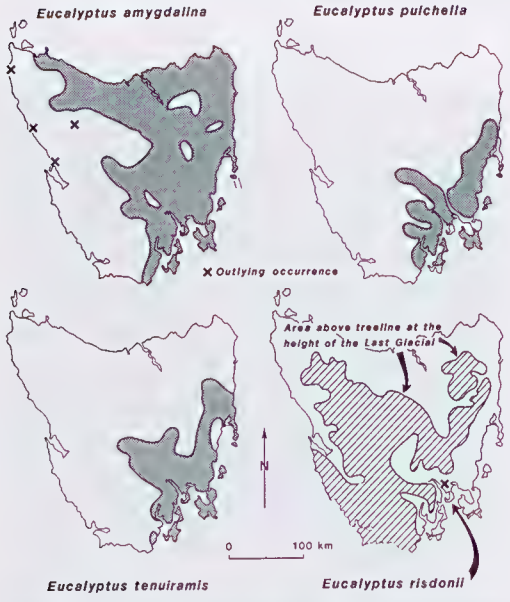

FIG. 1 — The distributions of Eucalyptus amygdalina, E. pulchella, E. risdonii *and* E. tenuiramis *generalised from the dot distribution maps in Kirkpatrick & Backhouse (1985), and the approximate location of the climatic treeline at the height of the Last Glacial (Kirkpatrick 1986).*

(fig. 1). The distribution of many of the endemic species suggests confinement to a southeastern glacial refuge (Kirkpatrick & Brown 1984, Potts & Reid 1985a). This is clearly seen in the endemic Piperitae species (informal subseries Amygdalininae, subgenus *Monocalyptus* — Pryor & Johnson 1971) where the endemics *E. risdonii*, *E. tenuiramis* and *E. pulchella* exhibit distinctly southeastern distribution patterns (fig. 1, Ladiges *et al.* 1983).

The lowland Piperitae species are strongly ecologically segregated in the southeast (e.g. Hogg & Kirkpatrick 1974). *Eucalyptus pulchella* is virtually confined to dry dolerite hills whereas *E. tenuiramis* and *E. risdonii* generally occur on soils developed on mudstone, although toward the east, *E. tenuiramis* may occur on dolerite hills where it grows with a glaucous (as opposed to green) variant of *E. pulchella*. *Eucalyptus risdonii* is geographically localized and occurs on the drier and shallower mudstone soils and appears to be a neotenous form of *E. tenuiramis* (e.g. Ladiges *et al.* 1983). *Eucalyptus amygdalina*, by contrast, is geographically widespread (fig. 1) and tends to be more an edaphic generalist, although in the southeast it generally occurs on soils derived from sandstone or mudstone. Further north however, *E. amygdalina* occurs on many sites which superficially appear suitable for *E. tenuiramis* or *E. pulchella* (e.g. Kirkpatrick & Brown 1984). In the case of *E. pulchella*, this apparent incomplete range expansion may be attributed to its inability to occupy soils formed on substrata other than dolerite (Hogg &

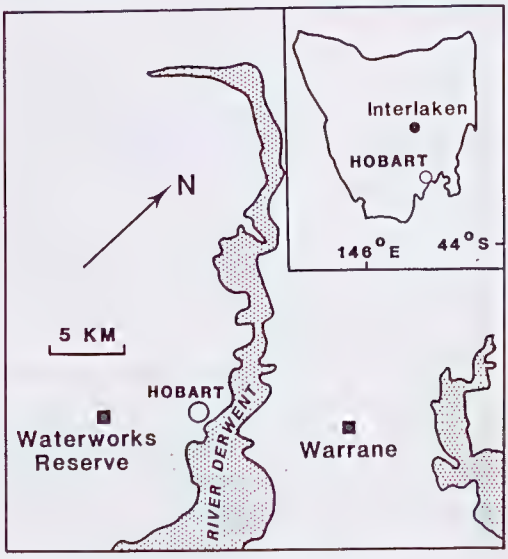

FIG. 2 — Locations of sample sites.

TABLE 1

The main characters defining the Tasmanian Piperitae species *Eucalyptus amygdalina*, *E. pulchella*, *E. tenuiramis* and *E. risdonii* from Curtis & Morris 1975).

Characters	*E. amygdalina*	*E. pulchella*	*E. tenuiramis*	*E. risdonii*
juvenile leaves	opposite sessile to shortly petiolate lanceolate pale green	opposite becoming alternate sessile to shortly petiolate linear green to subglaucous	opposite perfoliate ovate-lanceolate very glaucous	opposite perfoliate ovate-lanceolate very glaucous
adult leaves	alternate shortly petiolate lanceolate to narrow linear 60-120 x 7-10 mm green to sub-glaucous	alternate shortly petiolate narrow linear to linear-falcate 50-120 x 3-5 mm green to sub-glaucous	alternate petiolate elliptical to lanceolate-falcate 50-160 x 1-35 mm glaucous	juvenile leaves usually persistent in adult stage pair 60-100 mm long glaucous
buds/umbel	5-12	5-12	7-23	5-15
buds	pedicellate clavate	shortly pedicellate clavate	shortly pedicellate clavate	pedicellate clavate
operculum	hemispherical	hemispherical	flattened to sub-conical	hemispherical
capsules	pyriform-truncate to nearly hemispherical 4–6 mm diameter	pyriform-truncate to nearly hemispherical 5–6 mm diameter	pyriform-truncate to hemispherical 7–11 mm diameter	pyriform-truncate to hemispherical 8–10 mm diameter
bark	rough fibrous, dark grey usually persistent sometimes deciduous on upper regions	deciduous trunk smooth white or with bluish streaks	deciduous trunk smooth greyish-white	deciduous trunk smooth ashy-grey colour cream streaks
habit	mallee or tree to 20 m	tree 6-15 m	9-25 m tree	mallee or tree to 15 m

Kirkpatrick 1974, Brown & Bayly-Stark 1977, Harris & Kirkpatrick 1982), the presence of a broad band of soils on sedimentary rocks between the southeastern and northern lowlands coupled with relatively poor dispersal ability and insufficient time since deglaciation (Kirkpatrick & Brown 1984). Yet, throughout the *E. amygdalina* forests on dolerite in the north and northeast of the state there can be found groups of trees with varying proportions of deciduous bark and with adult leaves as narrow as those of *E. pulchella*. *Eucalyptus pulchella* and *E. amygdalina* are virtually identical in reproductive characters. Vegetative and bark characters define their difference (table 1). The few of these trees that have totally deciduous bark appear identical to the trees in the populations of *E. pulchella* in southeastern Tasmania.

The degree of isolation of these intermediates from populations of *E. pulchella* made the hypothesis of long distance hybridization particularly relevant. This paper addresses the problem of the origin of these intermediate populations by comparing the characteristics and variability of the progeny of one stand of isolated intermediates with those of the progeny of the putative parent species and with those of the apparent hybrids that occur where these two species have contiguous distributions.

METHODS

Collections of adult leaves and mature capsules were made from five trees of *Eucalyptus amygdalina* on mudstone at Warrane (AmW), five trees of *E. pulchella* on mudstone at Warrane (PmW), seven apparent hybrids between the two species from mudstone at Warrane (HmW), five trees of *E. pulchella* from dolerite at Warrane (PdW), five trees from a population of isolated intermediates on dolerite on the Interlaken-Tunbridge road (HdI), and from one tree of *E. pulchella* (PsR), one tree of *E. amygdalina* (AsR) and one adjacent putative hybrid between the two species (HsR) on sandstone at the Waterworks Reserve, Hobart (fig. 2). Length and width were measured for five sun leaves taken from the region of maximum spring/summer growth per tree.

Seedlings of the above trees were grown by parent in ten totally randomized blocks of thirty with two seedlings in each pot. A loam-based potting mix was used. After three months of growth in a glasshouse the following measurements were made on each seedling: height; number of fully expanded nodes on the main stem; number of lateral shoots with expanded leaves; length of the longest lateral shoot; first leaf pair with an intranode; the length of the internode between the fifth and sixth leaf pairs; length, and width of one of each of the second, fourth and sixth leaf pairs. The number of seedlings per parent varied from 6 to 20, but for most parents was between 18 and 20. A few obvious 'runts' (i.e. stunted plants) were excluded from measurement. Such plants are frequently found at low frequencies in eucalypt progenies (e.g. Potts & Reid 1983) even from pure species. In the present case there was no marked difference between populations in the frequency of these plants.

Means and coefficients of variation were calculated for the ratio between the length and width of the fourth leaf pair, internode length, seedling height, the ratio between the length of the longest lateral shoot and height, the ratio between the number of lateral shoots and twice the number of expanded nodes on the main stem, and the number of expanded nodes. Means for the leaf length/width at node four and intranode development from 18 progeny from each of four trees of *E. risdonii* and one tree of *E. tenuiramis* were available from a previous experiment conducted in similar conditions (Potts & Reid 1985b).

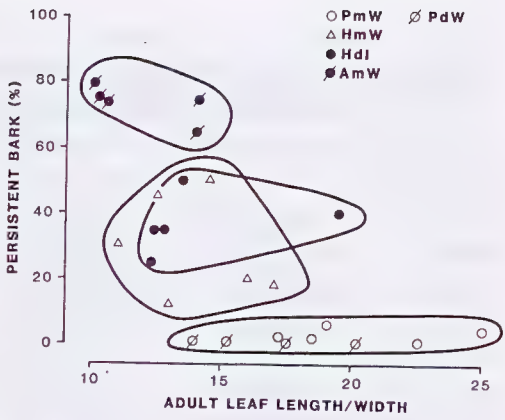

FIG. 3 — The pattern of variation in the adult phenotype (P = Eucalyptus pulchella, A = E. amygdalina, H = intermediate or hybrid, m = mudstone, d = dolerite, W = Warrane, I = Interlaken).

RESULTS

Adult Morphology

The population of intermediates (HdI) and the putative hybrids (HmW) clearly lie between the populations of *Eucalyptus amygdalina* and *E. pulchella* in the differentiating characteristics of the adult phenotype (fig. 3).

Seedling Morphology

There was no overlap in progeny means between *Eucalyptus amygdalina* (AmW) and the two *E. pulchella* populations in leaf length/width at the fourth node, internode length and the proportion of seedlings with intranodes and there was little overlap in the number of expanded nodes (fig. 4). The progenies from the population of isolated intermediates (HdI) were distinct from the *E. pulchella* progenies in these characters. They had extreme mean values for several variables (fig. 4), but for most characters differentiating *E. amygdalina* and *E. pulchella*, the HdI progenies clearly had close affinities to *E. amygdalina* (fig. 5). The progeny means of the putative hybrids from Warrane (HmW) varied between and even transgressed the range of variation between *E. pulchella* and *E. amygdalina*. Rather than lying intermediate between *E. pulchella* and *E. amygdalina*, the progeny means tended to lie close to one or other putative parent. HsR, the putative hybrid between

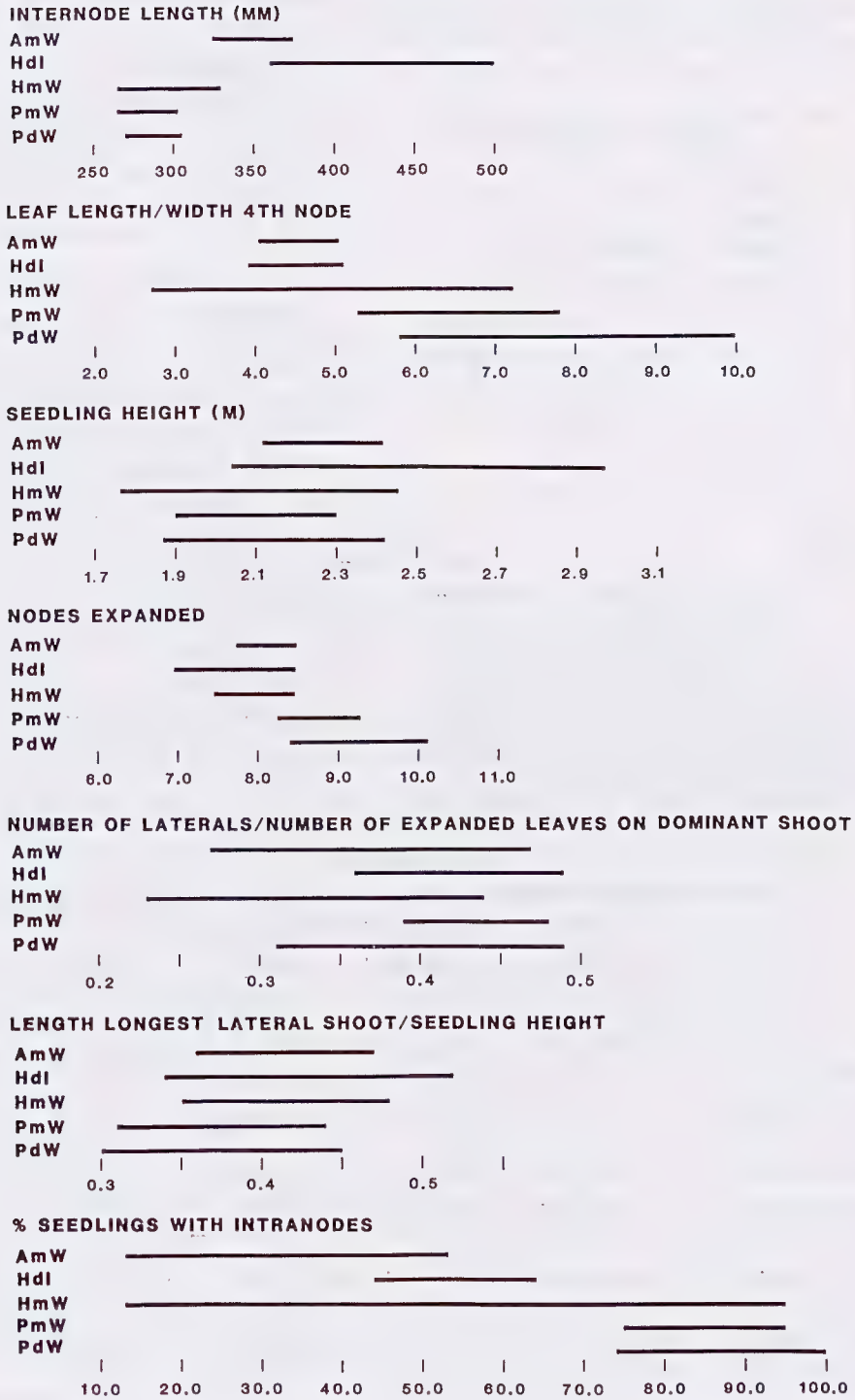

FIG. 4 — Ranges of progeny means by parent for six characters (P = Eucalyptus pulchella, A = amygdalina, H = *intermediate or hybrid, m = mudstone, d = dolerite, W = Warrane, I = Interlaken)*

E. amygdalina and *E. pulchella* at Waterworks, was also extreme in its seedling morphology, its mean values seldom lying between those of the progeny of the putative parents sampled at the same site (AsR and PsR, see fig. 5). HsR and at least one other putative hybrid from Warrane (HmW) had progeny means that lay between those of *E. amygdalina* and those of *E. tenuiramis/risdonii*. Sharp breaks between *E. tenuiramis/risdonii*, *E. amygdalina* and *E. pulchella* progeny means are evident in figure 5, with only the gap between *E. amygdalina* and the *E. tenuiramis/risdonii* group being occupied by putative hybrids, none of which are from population HdI.

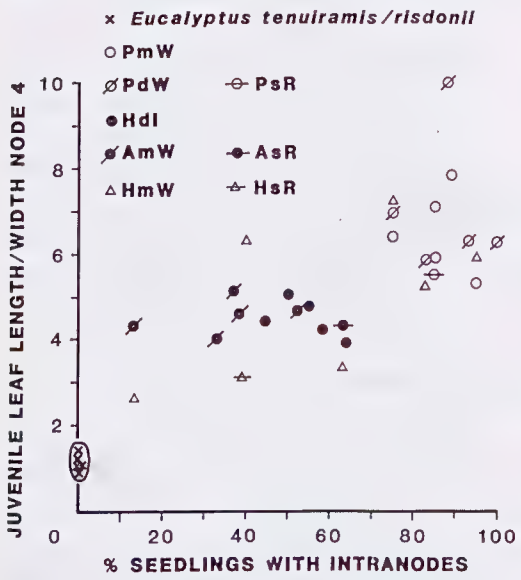

FIG. 5 — Progeny means by parent for the two seedling characters that best differentiate E. amygdalina *from* E. pulchella *(P =* Eucalyptus pulchella, *A =* E. amygdalina, *H = intermediate or hybrid, m = mudstone, d = dolerite, s = sandstone, W = Warrane, R = Waterworks, I = Interlaken).*

Seedling Variability

The progenies of the presumed hybrids from Warrane (HmW) and the Waterworks (HsR) proved generally much more variable than those of any other populations included in the experiment (table 2). The significance of this general difference was tested by noting the number of times the coefficients of variation for the progenies of the eight trees from HmW and HsR fell in the top third of values for each of six characters (those in fig. 4 except intranode presence). The actual value was 22 with an expected value of 13.75, giving a value of Chi-squared from a 2 x 2 contingency table of 9.5 (d.f. = 1, $p < 0.005$). The progenies from population HdI were no more variable than those from AmW, PmW or PdW (table 1).

In the character that best differentiates the seedlings of *Eucalyptus amygdalina* and *E. pulchella* (leaf length/width at node four) the progenies of trees from each of AmW, HdI, PmW and PdW vary in their variability, but it is only in progenies

TABLE 2

Means of progeny means and means of progeny coefficients of variation for selected seedling characters by group.

	AmW (5)		HdI (5)		HmW (7)		PmW (5)		PdW (5)	
	M	CV	M	CV	M	CV	M	CV	M	CV
Leaf length/width node 4	4.52	21.9	4.46	17.6	4.99	23.1	6.48	25.2	7.06	21.8
Internode length (cm)	34.5	28.3	42.8	27.3	28.6	28.6	27.8	28.3	28.5	27.7
Height (m)	2.26	0.316	2.59	0.276	2.04	0.314	2.12	0.334	2.18	0.283
No. of expanded nodes	7.97	16.4	7.77	17.5	8.13	17.5	8.81	18.3	9.03	15.8
No. of laterals/ no. of nodes	0.39	45.7	0.41	47.4	0.33	61.3	0.41	44.8	0.43	43.3
Length longest lateral/height	0.46	31.4	0.45	33.6	0.43	40.5	0.37	36.6	0.37	32.6

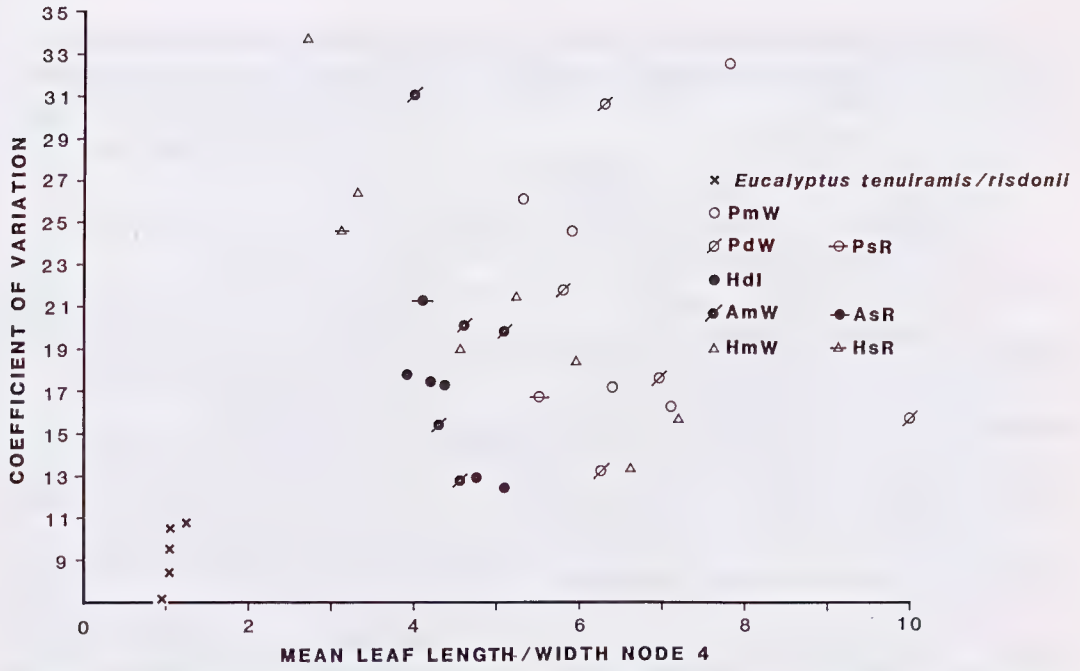

FIG. 6 — Variation in the variability about progeny means by parent for seedling leaf length/width at node four (P = Eucalyptus pulchella, A = E. amygdalina, H = intermediate or hybrid, m = mudstone, d = dolerite, s = sandstone, W = Warrane, R = Waterworks, I = Interlaken).

intermediate between *E. amygdalina* and *E. tenuiramis/ risdonii* that there appears to be a peak of variability (see HmW and HsR, fig. 6).

DISCUSSION

The experimental results do not necessarily support the hypothesis that *Eucalyptus pulchella* and *E. amygdalina* hybridize (Kirkpatrick *et al.* 1980, Potts & Reid 1983), although they provide strong supporting evidence for hybridization between *E. amygdalina* and *E. tenuiramis/ risdonii* (Potts & Reid 1985b). There is no evidence in figures 5 and 6 to suggest that *E. pulchella* and *E. amygdalina* hybridize at the Waterworks or at Warrane. Progeny means from intermediate adult trees from these areas tended to lie close to either *E. pulchella* or *E. amygdalina*. This could result from advance generation hybridization or result from the backcrossing of F1 trees exclusively to one or other parent. However, the more likely interpretation is that individuals of *E. pulchella* can develop some rough bark, and that individuals of *E. amygdalina* can be relatively smooth-barked, either through selective processes in the absence of *E. tenuiramis* or *E. risdonii* (as in the case of HdI), or as a result of the infiltration of genes from these latter two species. *Eucalyptus pulchella* and *E. amygdalina* differ little in seedling morphology when compared to their difference from *E. tenuiramis/risdonii* and the infiltration of genes from this complex may have an over-riding effect on progeny variability. This influence may account for the fairly high variability in several progenies from *E. pulchella* and *E. amygdalina* trees growing on mudstone at Warrane (fig. 6) and, unless more specific characters can be found, conclusive evidence of natural hybridization between *E. amygdalina* and *E. pulchella* requires the absence of *E. risdonii* and *E. tenuiramis* from the study area.

The isolated intermediate population (HdI) clearly has close affinities to *E. amygdalina*. The lack of intermediacy in juvenile characters and the low degree of progeny variability found for intermediate trees from this population would suggest that this stand has not arisen from recent hybridization through long distance dispersal nor does it appear to be a recent phantom hybrid population. This population is best regarded as the product of selection for narrow leaves and smooth bark within the gene-pool of *E. amygdalina*. *Eucalyptus amygdalina* and *E. pulchella* are very closely related (Pryor & Johnson 1971, Marginson & Ladiges 1982, Ladiges *et al.* 1983) and the convergence of some allopatric populations of *E. amygdalina* toward the *E. pulchella* phenotype (at

least in adult characters) presents the possibility that the edaphic specialist *E. pulchella* is an extension of this trend.

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STREAMFLOW CHARACTERISTICS OF NORTHEASTERN TASMANIA: I. REGIONAL FLOOD FLOWS

by A. D. Knighton

(with four tables and seven text-figures)

KNIGHTON, A.D., 1987 (30:vi): Streamflow characteristics of northeastern Tasmania: I. Regional flood flows. *Pap. Proc. R. Soc. Tasm.*, 121: 23-33. ISSN 0080-4703. Department of Geography, University of Sheffield, Sheffield, United Kingdom SI0 2TN.

Based on streamflow records from thirteen stations, regional equations are developed which enable the estimation of mean annual discharge and various flood flows at ungauged sites along rivers in northeastern Tasmania. The area around Swansea is shown to be hydrologically distinct, at least as far as flood discharges are concerned, and the analysis subsequently focuses on the rest of the region. Despite the wide range of climatic and physiographic conditions there, relationships are highly significant, with drainage area explaining more than 97% of the variation in flood discharge. Rates of change are not only relatively high but increase with flood magnitude, suggesting rapid downstream transmission of flood waters. Network magnitude may be a viable alternative to drainage area as an estimator. Its use has the advantage that the downstream pattern of flow addition can be readily charted for major rivers, as illustrated for the Ringarooma and George.

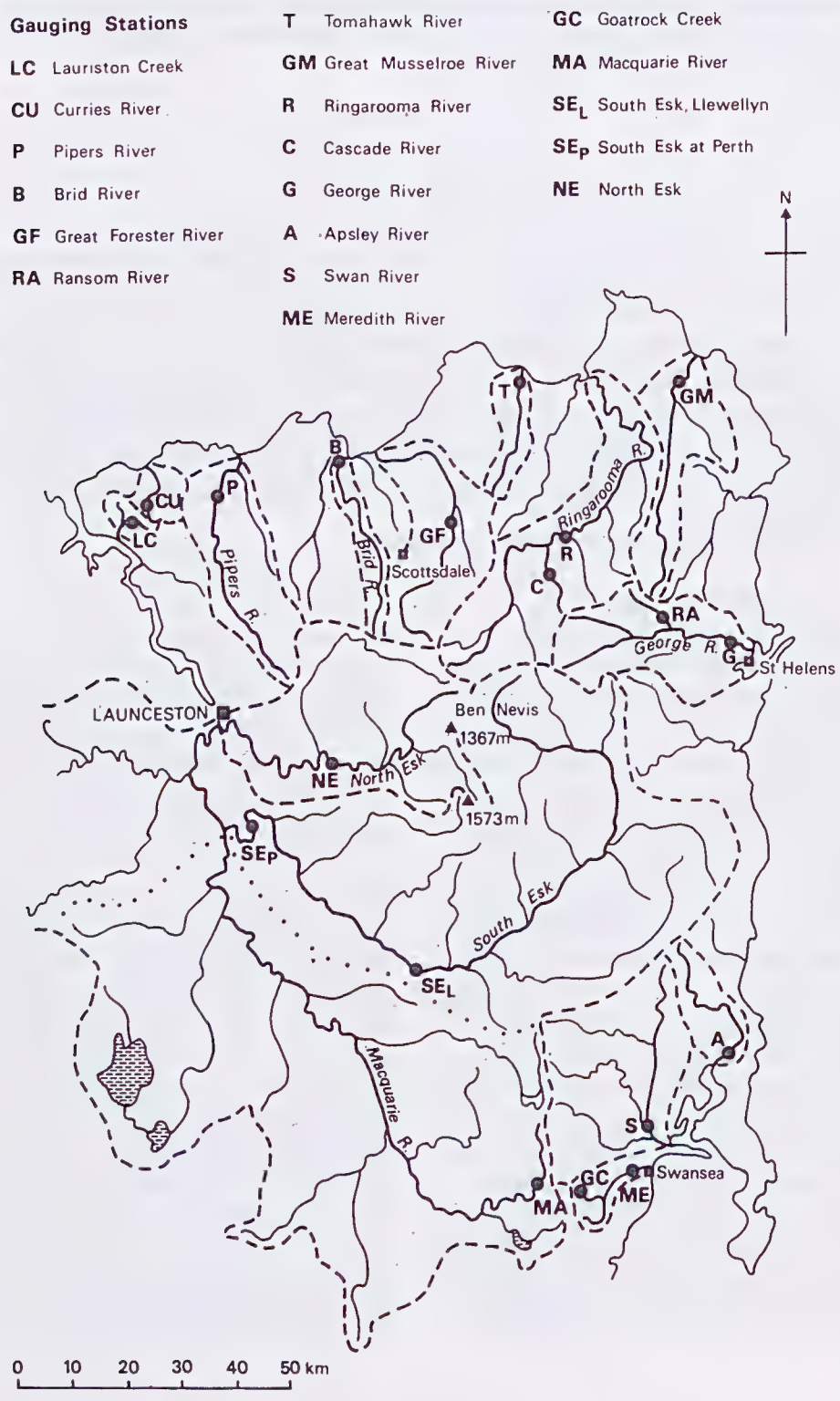
Key Words: Tasmania, stream flow, drainage area, flood discharge.

INTRODUCTION

The basic variable used to express the size and erosive effectiveness of natural rivers is discharge, which is generally measured at established gauging stations. However, the number of measurement sites within an area is usually quite small and rarely does a sequence of gauging stations exist along an individual river. Consequently, in order to extend a spatially limited data base and provide estimates of flow characteristics at ungauged sites, some form of regional analysis is necessary. The estimates so derived can be used for water management and river engineering purposes at regional and basin scales, as well as for routing water and sediment through individual catchments. Indeed the latter provided the initial stimulus for this study in that reliable flow estimates were required as a spatial series along the Ringarooma and George Rivers in order to model the movement patterns of material introduced from mining sources. Although so inspired, the results presented below have implications for a wider range of purposes.

The study falls into two parts, the first of which is concerned with flood flow estimation and the second with hydraulic geometry relationships. Both deal with rivers in northeastern Tasmania, a somewhat arbitrarily defined area bounded in the west by a line along the Tamar estuary, South Esk and Macquarie Rivers (fig. 1). The southern limit is defined by the southern-most sweep of the Macquarie River. Regional flow analyses are a compromise to a certain extent: between a larger sampled area with more gauging stations and a smaller one in which flow conditions are likely to be more homogeneous. Thus enlargement of the sampled area to augment the data base increases the degree of heterogeneity and the attendant risk of sampling from different hydrogeographic populations. Such proved to be the case here.

The area can be divided into three main sections. That to the north of the South Esk basin has rivers draining to the east and north coasts and to the Tamar estuary, so that they come under a wide range of climatic and physiographic influences. Mean annual precipitation is at a maximum (>1600 mm) to the north and northeast of Ben Nevis, where many rivers (notably the North Esk, Ringarooma, George and South Esk) have their headwaters. The first three rivers listed provide a west-east sample across this northern section, the pattern of their mean monthly discharges being distinctively seasonal (fig. 2) and typically temperate oceanic (Shaw 1983). Despite the broadly similar regimes with July-September and January-March being respectively the maximum and minimum flow periods, small but possibly significant differences are apparent in the monthly runoff patterns, particularly between the George and the other two rivers. Even when dealing with averaged


Gauging Stations
LC Launiston Creek
CU Curries River
P Pipers River
B Brid River
GF Great Forester River
RA Ransom River
T Tomahawk River
GM Great Musselroe River
R Ringarooma River
C Cascade River
G George River
A Apsley River
S Swan River
ME Meredith River
GC Goatrock Creek
MA Macquarie River
SEL South Esk, Llewellyn
SEP South Esk at Perth
NE North Esk
N
Pipers R.
Brid R.
Ringarooma R.
George R.
Scottsdale
St Helens
LAUNCESTON
Ben Nevis
1367m
1573m
North Esk
South Esk
Macquarie R.
Swansea
0 10 20 30 40 50 km

flows in neighbouring basins, flow behaviour can be variable.

The South Esk basin dominates the area with the main river describing a horseshoe-like course (fig. 1) along which mean annual precipitation varies from 1600 mm in the upper reaches to less than 600 mm south of Perth. The main tributary, the Macquarie River, has a southern origin and enters the South Esk downstream of Perth, the site of the gauging station with the largest drainage area used in this study. In effect the South Esk basin separates the northern section from a southern one represented by a cluster of gauges in the neighbourhood of Swansea (fig. 1). There, mean annual precipitation ranges from 650 to 900 mm. As the following analysis will show, this southern section has streamflow properties which are distinct from those further north.

REGIONAL ANALYSIS

The estimation of flood frequency or hydrograph parameters at ungauged sites commonly relies on statistical relationships between river flow and catchment characteristics. The latter can be broadly grouped into climatic, surface cover (soils and land use) and drainage basin properties, categories which include a potentially large number of operational variables. Ease and reliability of measurement, and likely success in prediction are appropriate criteria in the choice of suitable variables. From the point of view of the first criterion, drainage basin properties are probably the most suitable provided reliable topographic maps are available at a large enough scale. Those properties can be further subdivided into:

(i) size variables — drainage area, mainstream length, total channel length;
(ii) slope properties of the channel and hillslope systems; and
(iii) channel network variables drainage density, stream frequency, network magnitude;

with drainage area and network magnitude being relatively easy to measure. As regards the second criterion, drainage area has consistently been an effective variable, one reason for its success being that it subsumes a great deal of relevant hydrological information. In probably the most comprehensive study of streamflow variation yet completed (NERC, 1975), drainage area proved to be the single most important variable influencing the mean annual flood ($Q_{2.33}$) at both national and regional levels of the British Isles. In assessing ten regional flood-frequency analyses from the United States, Riggs (1973) found that drainage area was

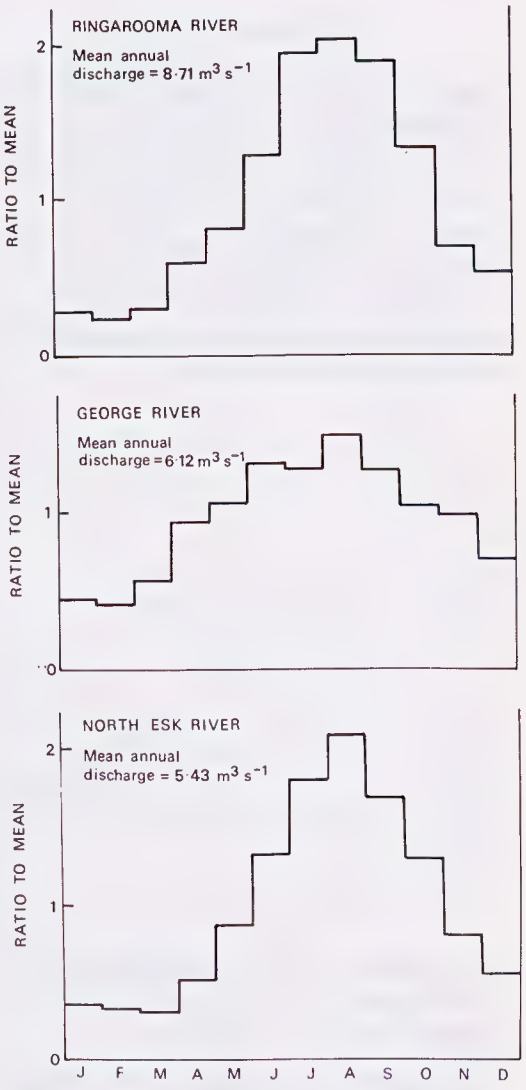


FIG. 2 — Flow regimes of the Ringarooma, George and North Esk Rivers expressed by the ratio of mean monthly to mean annual discharge.

the most consistent out of 16 independent variables since it was the only one to appear in all ten analyses. Given also that drainage area has been successfully used to predict the median flood (Q_2) in western Tasmania (Watson 1975, Watson & Williams 1983), its choice for this study seems obvious, especially since this study is largely of an exploratory nature. Following standard practice, least-squares regression analysis is used to derive the required relationships which are assumed to have the typical log-linear form.

Mean Annual Discharge

Mean annual discharge is simply the arithmetic average of all daily mean flows, with a frequency of 29, 32.5 and 30% respectively at the North Esk, Ringarooma and George gauging stations. In most humid areas it is closely related to drainage area and mean annual precipitation. Here, its relationship to drainage area is highly significant with a coefficient of determination (ρ^2) of 0.98 and a standard error of estimate of 0.11 (fig. 3). Basins of less than 30 km² rarely figure in such plots but there are three in this area and they plot well relative to other points.

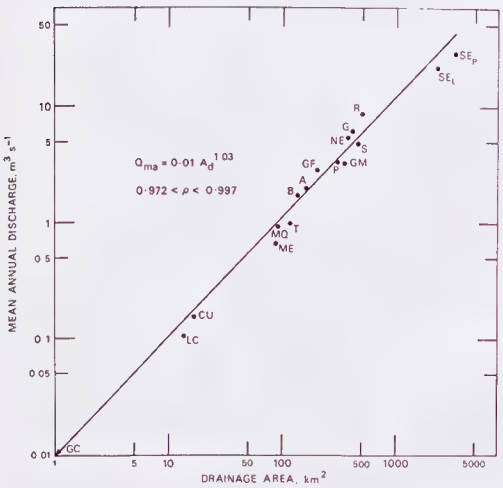


FIG. 3 — Relationships of mean annual discharge to drainage area. The 95% confidence limits for the correlation coefficient are given.

Over much of the eastern United States where total precipitation varies gradually with distance and each unit area contributes about the same volume of runoff, mean annual discharge tends to have a one-to-one relationship with drainage area (Dunne & Leopold 1978). Such is the case here despite the less uniform pattern of rainfall. Indeed quite steep precipitation gradients exist from the coastal and South Esk valley areas toward the northern highlands. In addition to an exponent value of almost one, the regression equation (fig. 3) has an intercept value which indicates that on average a mean annual discharge of 0.01 $m^3 s^{-1}$ is produced from a unit basin area.

Such is the dominance of drainage area that no improvement in the level of explanation was achieved by the inclusion of mean annual precipitation as an additional independent variable. Nevertheless, most of the residuals above the regression line have higher than average precipitation, while those below have lower than average. That the two South Esk stations plot as negative residuals can be partly attributed to the precipitation effect, although channel storage may be a contributory factor at these large drainage areas. However, exclusion of those stations to give

$$Q_{ma} = 0.01\ A_d^{1.02} \qquad (1)$$

has obviously little effect on a well-defined regional trend which is maintained over three and a half cycles of logarithms.

Flood Discharges and Drainage Area

The main part of this paper is concerned with higher magnitude flows which are more relevant hydrologically and morphologically. Flood frequency analysis is a procedure for estimating the peak discharge which on average is likely to be equalled or exceeded once in a specified period of T years. Thus Q_T is the peak flow having a return period or recurrence interval of T years. Before proceeding to the regional stage, the magnitudes of specified flood flows had to be determined for each of the gauging stations.

One basis for flood frequency analysis is the annual maximum series which takes the single peak discharge in each year of record so that the number of data values equals the record length in completed years. Ten years is generally regarded as the minimum period for analysis and, with one exception, this prescription was followed (table 1). Lauriston Creek was specifically included to extend the data base into the lower end of the drainage area range where there are few data but, despite only seven years of record, the additional error involved is probably quite small, particularly in the estimation of average floods. Having ranked the annual peak flows and calculated their recurrence intervals from (n+1)/r (where n is the number of years of record, r is the rank of a particular flood), a suitable frequency distribution has to be chosen. There is no unequivocal theoretical basis for choosing the correct distribution to describe an annual maximum series but the log-Pearson Type III is widely accepted (Benson 1968, NERC 1975) and, in common with Watson (1975), it was used here because of its objectivity. Generally it provided a good fit to the data, although several of the plots had a hint of sinusoidal autocorrelation within the residuals. The graph for the North Esk (fig. 4)

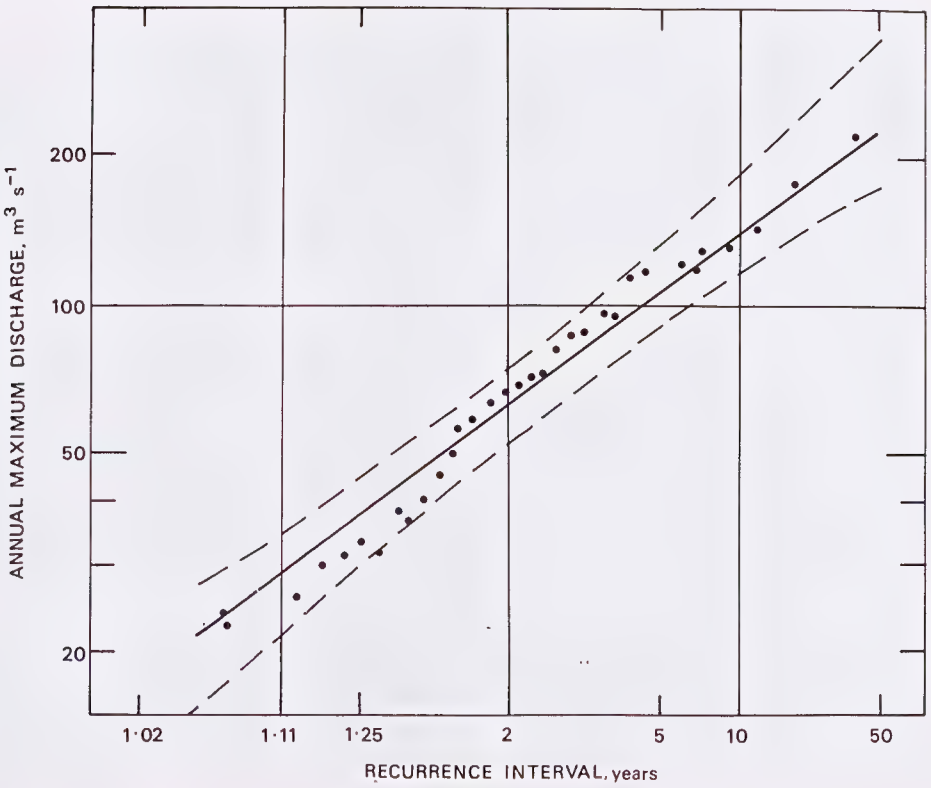


FIG. 4 — Flood-frequency plot for the North Esk at Ballroom, 1950–1983. The 95% confidence limits are shown.

TABLE 1

Flood flow data.

Gauging station		Length of record	Flood discharges, $m^3 s^{-1}$ record,			
Index number	River	years	$Q_{1.11}$	Q_2	Q_5	Q_{10}
302200	Swan	20	97	490	892	1123
302204	Apsley	15	82	188	325	433
302205	George	11	46	116	213	292
302208	Meredith	16	28	97	163	199
302210	Great Musselroe	13	30	70	123	165
302213	Goatrock Creek	10	0.9	1.8	2.9	3.6
318017	South Esk at Llewellyn	25	204	523	971	1341
318204	North Esk	34	29	64	108	142
318208	South Esk at Perth	27	174	491	972	1390
318215	Lauriston Creek	7	2.3	4.1	6.2	7.6
319200	Brid	14	11	25	42	56
319202	Tomahawk	13	15	24	33	40
319204	Pipers	11	23	62	118	165

The index number is the one used by the Rivers and Water Supply Commission of Tasmania.

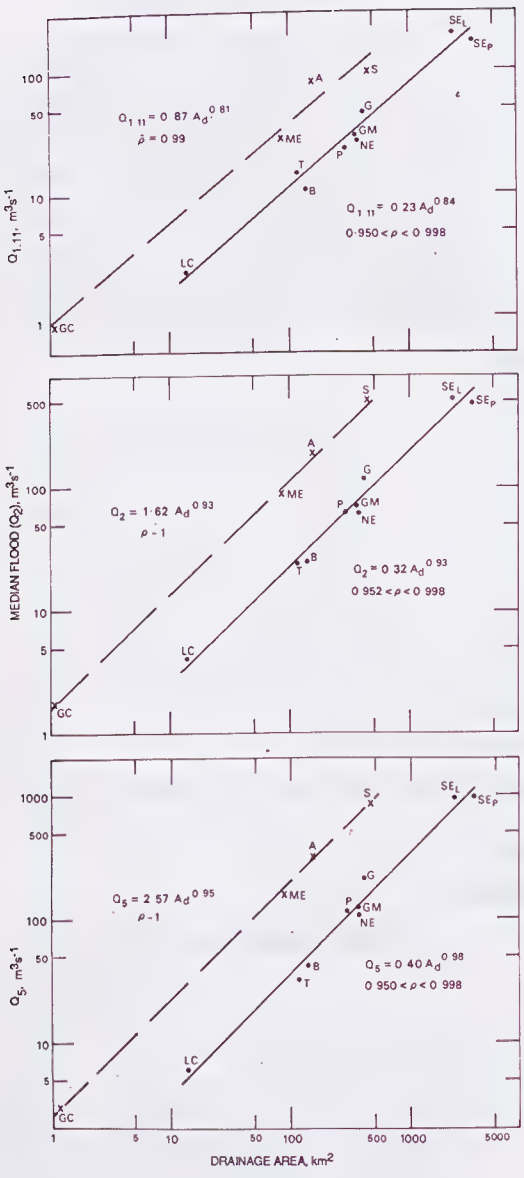


FIG. 5 — Relationships of flood flows, $Q_{1.11}$, Q_2 and Q_5, to drainage area for a southern and a northern/central section of northeastern Tasmania. The 95% confidence limits for the correlation coefficient are given.

illustrates these points, as well as showing how the 95% confidence limits begin to widen away from a recurrence interval of two years which defines the median annual flood (Q_2). The mean annual flood has a recurrence interval of 2.33 years and the ratio of $Q_{2.33}/Q_2$ at the 13 gauging stations is fairly stable with a mean of 1.12 and a standard deviation of 0.02. These average flows are important since it is believed that discharges in the neighbourhood of bankfull cumulatively perform most work in natural rivers and therefore are largely responsible for forming the channel (Knighton 1984).

A preliminary analysis in terms of the ratio Q_2/Q_{ma} suggested that the 13 stations cover two rather than one hydrogeographic province, with the southern stations on the Swan, Apsley, Meredith and Goatrock Creek forming a separate group. The mean ratio there was 126 compared with 21 for the remaining stations. The subsequent plots confirmed the distinction (fig. 5), and the two areas were henceforth treated separately. Thus, while the initially selected region can be described by a single equation as regards mean annual discharge, the same homogeneity does not apply to flood flows. Indeed, comparing intercept values, flood flows in the southern section are about five times larger than elsewhere.

All relationships are highly significant (table 2), even for the southern section where the data set is small. In fact, apart from $Q_{1.11}$, the four stations fit almost exactly along straight lines on log-log graph paper (fig. 5) and standard errors are very low. The results for Q_{10} are included largely for completeness since the records are not consistently long enough for good estimation of that flow, although the relationships retain the same level of significance. Thus table 2 provides two sets of equations which can be used for estimating a range of flood flows in the rivers of northeastern Tasmania. By way of example, the gauging station on the Ringarooma has seven years of record, the analysis of which gives a median flood value of 100 $m^3\ s^{-1}$. The corresponding regional equation estimates the flow at 105 $m^3\ s^{-1}$.

The form of the discharge-drainage area equation changes systematically with increasing recurrence interval, both the intercept value (a) and regression coefficient (b) becoming larger (table 2). This is the case in both sets of equations. The increase in intercept value is to be expected given that the sequence of relationships refers to progressively larger flood discharges and the intercept indicates the flow at a unit area, but it is interesting to note that the rate of increase between successive flows becomes less. However, more unusual is the progressive increase in regression coefficient. Ordinarily it decreases (table 3) because greater channel and valley storage attenuate the flood wave at higher flows. That the reverse is found here

TABLE 2

Flood flow-drainage area relations, northeastern Tasmania.

Flood discharge	Equation constants a	b	Correlation coefficient	Standard error of estimate
(i) Northern area — nine stations				
$Q_{1.11}$	0.23	0.84	0.99	0.10
Q_2	0.32	0.93	0.99	0.09
Q_5	0.40	0.98	0.99	0.10
Q_{10}	0.45	1.01	0.99	0.11
(ii) Southern area — four stations				
$Q_{1.11}$	0.87	0.81	0.99	0.16
Q_2	1.62	0.93	0.99	0.03
Q_5	2.57	0.95	0.99	0.03
Q_{10}	3.24	0.95	0.99	0.03

Symbols: $Q = a A_d^b$.

TABLE 3

Flood flow-drainage area relations.

Source	Location	Drainage area, km²	Discharge	a	b
Benson (1962)	New England, USA 164 stations	4-25 070	$Q_{2.33}$	0.56	0.85
			Q_5	0.97	0.82
			Q_{10}	1.51	0.79
Thomas & Benson (1970)	Potomac River basin, USA	15-30 000	Q_2	0.86	0.80
			Q_5	1.74	0.78
			Q_{10}	2.80	0.76
NERC (1975)	British Isles 533 stations	0.05-9 868	$Q_{2.33}$	0.68	0.77
Watson (1975)	Western Tasmania 7 stations	449-2 539	Q_2	4.70	0.74
Watson & Williams (1983)	Western Tasmania 10 stations	15-2 539	Q_2	5.19	0.75

Symbols: $Q = a A_d^b$.

may be due to the low levels of storage available so that translation rather than reservoir effects dominate the downstream transmission of flood waters. Comparing tables 2 and 3, it appears that northeastern rivers do indeed increase their flood volumes downstream at a faster rate than do rivers in similar environments. On the other hand, the intercept values for the northern area are relatively small, particularly when compared with western Tasmania which is wetter, steeper and more densely drained. Those for the southern area are reasonably high, suggesting a greater capacity for flood flow generation within that group of streams.

The amount of scatter about the regression lines is small (fig. 5). In the northern area graphs the George and South Esk (Llewellyn) stations consistently appear as positive residuals, with the Brid, North Esk and South Esk (Perth) stations as

negative residuals. This variation, although relatively small, points to inter-basin contrasts in flood generation and transmission. The two South Esk stations seem to be in the wrong order as regards flood volumes (table 1, fig. 5), possibly because water movement to the Perth station is more subject to the influence of temporary storage. However, exclusion of that station from the regressions had little effect on the form of the equations which, considering the range of environmental conditions covered, describe the data very well.

Flood Discharges and Network Topology

Intuitively it seems reasonable to argue that the way in which channels of different size are linked together within the drainage network can influence the movement pattern of flood waters and therefore the resultant flood volumes, especially at downstream locations. Certainly the Flood Studies Report (NERC 1975) includes stream frequency (number of channel segments per unit area) as an important explanatory variable of the mean annual flood and attempts have been made to relate parameters of the Instantaneous Unit Hydrograph to network variables (Rodriguez-Iturbe & Valdes 1979). There, however, the emphasis has been on Horton-Strahler rather than Shreve-Smart measures of drainage network composition. A major element in the more recent Shreve-Smart approach is the introduction of new topologic parameters which describe network structure in dimensionless terms. Two are considered here — magnitude and diameter. The magnitude of a channel link, an unbroken section of channel between successive nodes (sources, junctions or outlet), is defined as the number of sources upstream, while diameter is the maximum link distance within the network. Both have geometric equivalents — namely, drainage area and mainstream length. Indeed magnitude (M) and drainage area (A_d) are related theoretically (Shreve 1967) by

$$A_d = KL^2 (2M-1) \qquad (2)$$

where L is the average link length and K is a coefficient, but magnitude is easier to measure provided suitable maps are available.

Map scale is known to affect channel delineation and therefore the calculation of network indices, so that it has become common practice to take the blue-line network shown on 1:25 000 maps as the initial basis for measurement. Unfortunately three of the nine northern stations are not yet covered by the new 1:25 000 series, which reduces

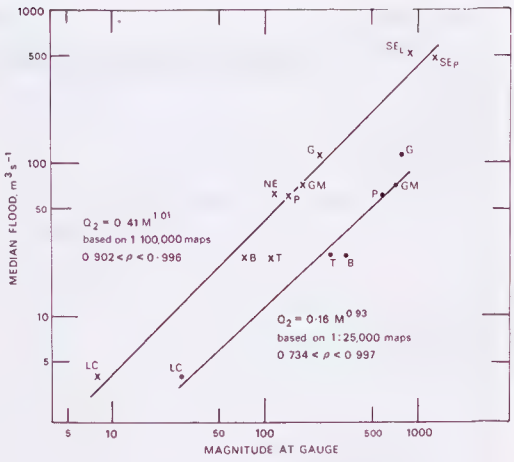


FIG. 6 — Relationship of the median annual flood to network magnitude measured at two map scales, 1:25 000 and 1:100 00.

the data set to six and excludes the upper end of the scale represented by the South Esk stations. Based on measurements of link magnitude (M) and network diameter (D) at each of the six gauges, the following equations were obtained for the median annual flood (Q_2)

$$Q_2 = 0.16\ M^{0.93}\ (\rho = 0.97, \text{SEE} = 0.13) \qquad (3)$$

$$Q_2 = 0.33\ D^{1.09}\ (\rho = 0.81, \text{SEE} = 0.34) \qquad (4)$$

Although significant at the 95% level, the latter does not describe the distribution of data particularly well and is henceforth disregarded as a possible means of flow estimation.

The exponent in equation (3) is exactly the same as in the corresponding drainage area relationship (table 2, fig. 5), which supports the belief that the rate of downstream increase in Q_2 along these northern rivers is faster than elsewhere. Again the Brid (northern coastal plain) appears as a negative residual and the George (sharply dissected and rugged headwaters) as a positive one, with the remaining points quite close to the line (fig. 6). For comparative purposes and to produce an equation applicable to those parts of the northern area outside that currently covered by the 1:25 000 series, magnitude was determined from 1:100 000 maps for the original nine northern stations and correlated with the median annual flood to give

$$Q_2 = 0.41\ M^{1.01}\ (\rho = 0.98, \text{SEE} = 0.14) \qquad (5)$$

The regression coefficient is slightly larger than in equation (3) but the intercept value is significantly

TABLE 4

Flood flow-network magnitude relations.

Flood discharge	Equation constants a	b	Correlation coefficient	Standard error of estimate
(i) 1:25 000 series — six stations				
$Q_{1.11}$	0.13	0.82	0.97	0.12
Q_2	0.16	0.93	0.97	0.13
Q_5	0.19	1.00	0.97	0.15
(ii) 1:100 000 series — nine stations				
$Q_{1.11}$	0.28	0.92	0.98	0.12
Q_2	0.41	1.01	0.98	0.14
Q_5	0.54	1.06	0.97	0.17

Symbols: $Q = aM^b$.

so, indicating that a unit stream at 1:100 000 has on average a magnitude of about 3 at the larger scale. Although equation (5) explains the data quite well (fig. 6), it is not considered to be as reliable as equation (3) because that is based on 1:25 000 maps which are both more recent and better defined as regards surface channels.

The fact that magnitude correlates reasonably well with Q_2 (and other flood flows, table 4) implies that it could be an effective alternative to drainage area as an estimator of flood discharge. In choosing between the two, likely success in prediction and ease of measurement have already been mentioned as appropriate criteria. Judging from the higher correlation and lower standard error of estimate, drainage area seems to be superior as a predictor but the magnitude relationship, which is based on fewer points, could be improved when the entire area is mapped at the 1:25 000 scale. As regards the second criterion, the measurement of drainage area is usually straightforward but can be time consuming if flow is to be estimated at many ungauged sites. On the other hand, magnitude is easily measured and, because network structure can be simply stored in a computer as a binary string, the magnitude of any point can be readily determined. The main requirement is consistency in the delineation of networks and their constituent channels.

The use of magnitude has a further advantage. Since each channel link within a network has a particular magnitude, the discharge of each link can be estimated and the pattern of flow addition from tributary sources traced for major rivers. Based on measurements of network structure and the regional discharge-magnitude relationship (equation 3), the downstream pattern has been plotted for the George and Ringarooma rivers (fig. 7). Scale limitations do not allow the smaller tributaries to be shown but there is sufficient detail to indicate major differences between the two river systems. Whereas the George is characterised by infrequent, large-scale additions of flow, concentrated in the middle section, the Ringarooma has a more regular pattern with smaller but more frequent tributary contributions along the entire length of the river. In part these differences can be associated with the more elongate form of the Ringarooma basin (fig. 1). Such plots emphasize the discontinuous nature of flow addition, which has implications for the transport of sediment and the adjustment of channel form. They may also provide a basis for more efficient water management and for routing flood flows through drainage networks.

CONCLUSION

Given that hydrologic response is influenced by many factors which are usually highly correlated and spatially variable, regional analyses based on equations having only one independent variable inevitably contain errors. Consequently flow estimation must be tinged with caution, especially if the available data base is relatively small as is the case here. Also, application of the results to longer time periods may be invalid if, as in New South Wales (Pickup 1976), the rivers are subject to fluctuating regimes over 30-50 year periods. Set against these reservations is the high level of significance achieved by the regional relationships for northeastern Tasmania, in which drainage area explains more than 97% of the variation in flood

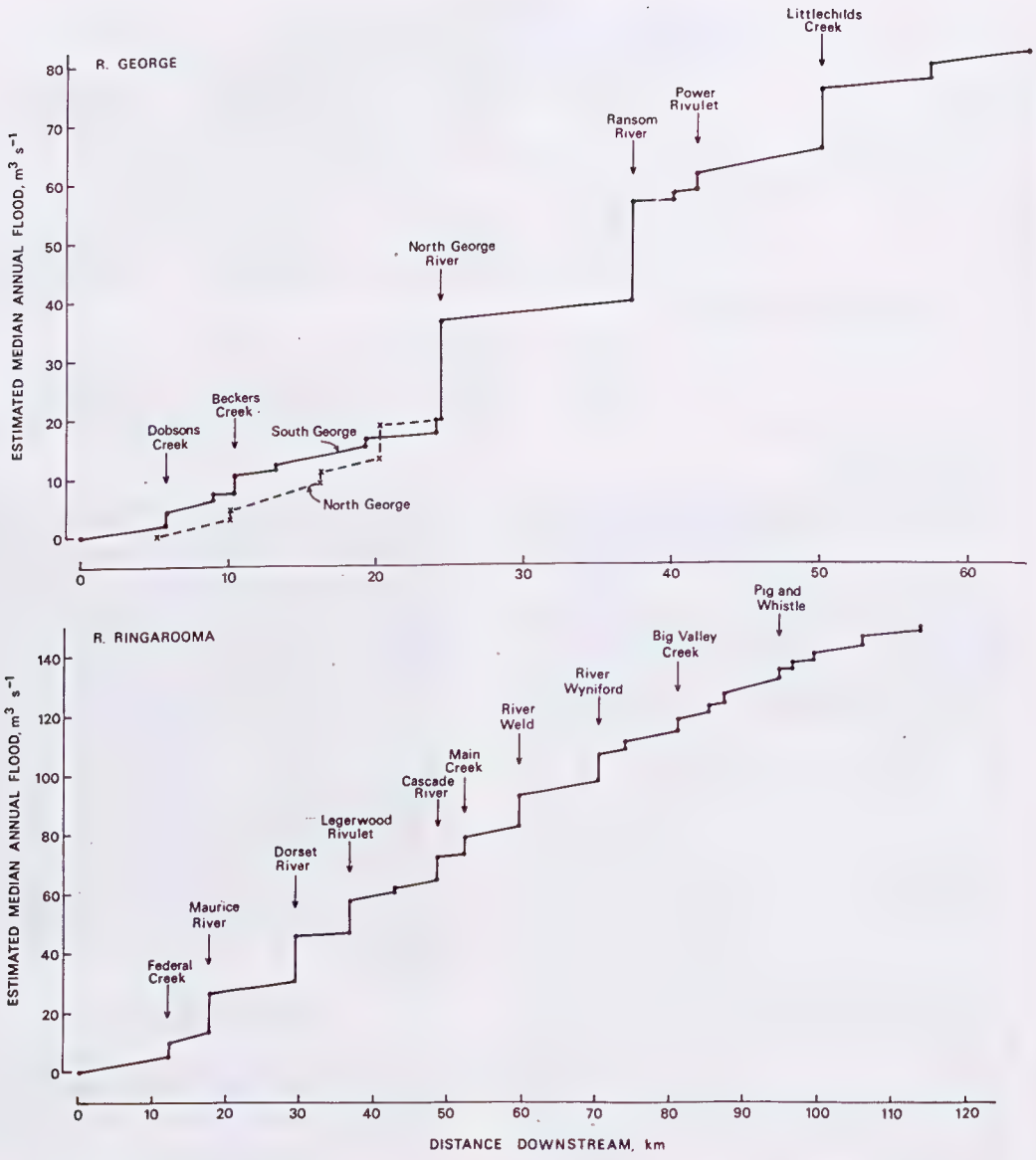


FIG. 7 — The downstream pattern of flow addition estimated from equation (3) for the George and Ringarooma Rivers.

discharges (table 2, fig. 5). Atypically the higher magnitude floods increase faster with drainage area than do the lower magnitude ones, which may reflect limited storage during the downstream transmission of flood water. The analysis has also shown that the rivers in the neighbourhood of Swansea are hydrologically distinct, with flood flows more than five times as large as those elsewhere in the area. Finer distinctions can be seen in the pattern of residuals from the northern regressions (figs 5 and 6). The George River, which drains one of the wettest catchments, and the South Esk at Llewellyn always appear as positive residuals, while the Brid and South Esk at Perth have the

opposite quality. The Great Musselroe and particularly the Pipers Rivers show very little deviation from the regression lines and from that point of view may be regarded as typical basins worthy of more intensive study.

Network magnitude appears to offer a viable alternative to drainage area as an estimator of flood flows in single-variable equations. Its use provides an opportunity for charting the pattern of flow addition along major rivers (fig. 7) and may improve estimation procedures by taking account of tributary inflows. However, any further application must await the completion of the 1:25 000 map coverage on which surface channels are better defined. Indeed the overall need is for more data to improve the reliability of results. The relationships obtained in this initial study should be re-evaluated in five years' time when the data base is more extensive through both an increased length of record and a larger number of suitable gauging stations.

ACKNOWLEDGEMENTS

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(accepted 15 September 1986)

A FOSSIL BOLSTER PLANT FROM THE KING RIVER, TASMANIA

by N. Gibson, K.W. Kiernan and M.K. Macphail

(with two tables, two text-figures and three plates)

GIBSON, N., KIERNAN. K.W. & MACPHAIL, M.K., 1987 (30:vi): A fossil bolster plant from the King River, Tasmania. *Pap. Proc. R. Soc. Tasm.*, 121: 35-42. ISSN 0080-4703. Departments of Geography and Botany (N.G.), Department of Geography (K.W.K.) and Department of Botany (M.K.M.), University of Tasmania, Hobart, Tasmania.

A macrofossil of the alpine bolster plant *Donatia novae-zelandiae* was found in the King River Valley, approximately 230 m above sea level in central western Tasmania. The fossil was in situ on a palaeosol that appears to have formed immediately prior to the late Last Glacial Maximum. An age of 21 180 + 370 years b.p. was established by radiocarbon dating. Pollen and present day distributional data suggest that the tree line was then at least 750 m lower than at present, implying a temperature depression of about 4.5° C. Scanning electron-micrographs and photomicrographs of the extant and fossil bolster species are presented.

Key Words: Tasmania, bolster, *Donatia*, fossil, palaeosol.

INTRODUCTION

Bolster plants are chamaephytes with a very compact growth habit, the branches being closely packed, with short internodes forming a hard hemispherical surface. This growth form is common in alpine areas of Tasmania, New Zealand, South America and some of the sub-Antarctic Islands (Godley 1978). The bolster form is poorly developed in the alpine areas of mainland Australia. The term bolster is preferred to cushion to indicate the hard compact nature of this growth form compared with Northern Hemisphere species of cushion plants.

In Tasmania there are four major species of bolster plant, *Abrotanella forsteroides* (Hook.f.) Benth. (Asteraceae), *Dracophyllum minimum* (Epacridaceae), *Phyllachne colensoi* (Stylideaceae) and *Donatia novae-zelandiae* (Donatiaceae). These species are initially difficult to distinguish in the field in the vegetative phase. They can form hard cushions up to 3.0 m diameter and 0.5 m tall. Distribution patterns found in these species have been described by Martin (1940), Jackson (1972), Kirkpatrick (1977, 1980, 1982, 1983) and Kirkpatrick & Harwood (1980), Brown *et al.* (1983), Kirkpatrick & Gibson (1984) and Gibson & Kirkpatrick (1985a,b).

The difficulty of ascribing the terms alpine and subalpine to the high altitude treeless areas of Tasmania, where treelines are generally absent, has been discussed by Kirkpatrick (1982). Notwithstanding this, bolster plant distribution in Tasmania is generally described as alpine with incursions below the climatic treeline in areas subject to cold air drainage and poor soil drainage. This paper records a macrofossil of the cushion plant *Donatia novae-zelandiae* from the King River Valley approximately 750 m below the present climatic treeline in central western Tasmania, and discusses its stratigraphic context and its significance in relation to present day distributional patterns.

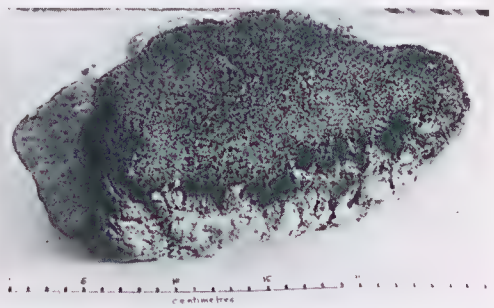

PLATE 1 — Photograph of a fossil Donatia novae-zelandiae *cushion (21 180 years b.p.) from the Dante Rivulet site.*

METHODS

The 200 mm diameter fossil was collected during an investigation of the glacial chronology of the central West Coast Range. It was obtained from a 5 m deep section cut by the King River a

short distance downstream from its confluence with the Dante Rivulet at about 230 m ASL (plate 1, figs 1 and 2). By this means it was possible to relate the fossil *Donatia* to the regional lithostratigraphy and chronostratigraphy. The immediate area has been subject to repeated firing, the present vegetation consisting of heathy sedgeland with riparian strips of mixed forest.

Positive identification of the fossil was carried out using both cuticular analysis and scanning electron microscopy of the leaf surface. Leaf fragments were initially soaked in hydrofluoric acid for 24 hours to remove siliceous material. The most intact fragments were mounted for scanning electron microscopy. The remaining material was cleared with nitric acid, and the cuticles prepared by soaking in nitric acid and potassium chlorate neutralising with aqueous ammonia and finally staining with safranin O and mounting. Comparative slides of all four extant bolster species were similarly prepared.

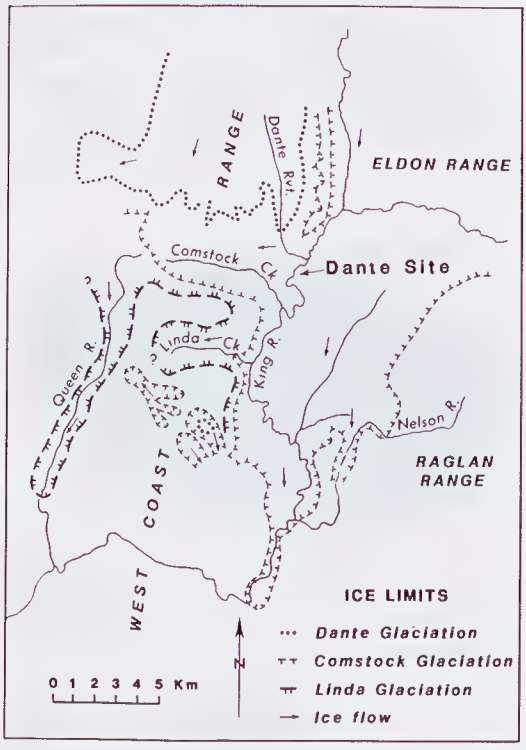

FIG. 1 — Topographic relationships and Quaternary ice limits near the Dante Rivulet site in the central West Coast Range (after Kiernan, 1983a).

A spot pollen sample was taken from the organic silts at the downstream end of the palaeosol. Pollen and spore types were extracted using standard palynological techniques (Faegri & Iverson 1975).

Species nomenclature follows Curtis (1963, 1967) and Curtis & Morris (1975), unless otherwise stated.

RESULTS

Stratigraphy

The exposed profile is shown in figure 2. The lowermost metre of the section consists of coarse gravels and gritty sand that probably represent part of the Comstock Formation but could be more recent. It is believed to represent glacial outwash derived from an ice body which lay a short distance upstream in the King Valley. This unit is unconformably overlain by 0.15 m of very dark brown (7.5 YR2/3) organic silt at the base of which abundant macrofossils were found including small branchlets which are believed to have been river transported. The spot pollen sample taken from this unit indicates an Asteraceae-Poaceae assemblage (table 1).

A weakly developed podsolic palaeosol occurs upon this silt unit. The intact cushion macrofossil was about 0.2 m in diameter and was found *in situ* on the palaeosol. The palaeosol is in turn overlain by 0.45 m of slightly discoloured yellowish grey (2.5 Y5/1) silt and fine sands which were probably rapidly deposited in an aquatic environment. The cushion plant itself has been radiocarbon dated at 21 180 ± 370 years b.p. (SUA2154). A 0.2 m piece of driftwood was recovered from 0.1 m above the palaeosol and dated at 18 800 ± 500 years b.p. (ANU2533). A further date of 20 100 ± 470 years B.P. (SUA2155) has been obtained from twigs incorporated in a silt bed that overlies the Comstock gravels about 100 m downstream from the fossil cushion. This silt is believed to be equivalent to that immediately beneath the cushion plant, but exposure is discontinuous and this relationship remains unproven (Kiernan 1980, 1985).

A further 0.35 m of yellowish grey (2.5 Y6/1) fine sand and silt is succeeded by three metres of gravels of the Dante Formation which are interpreted as glacial outwash from a new ice advance in the tributary Dante Rivulet. The section is overlain by a metre of peat (Kiernan 1980, 1983a).

Pollen Analysis

Table 1 lists pollen and spore types extracted from the organic silt. Included against each taxon

TABLE 1

Spot pollen sample from Dante palaeosol and an estimate of pollen production/dispersal characteristics.

NI = no information, SU = severely under-represented, U = under-represented, W = well to over-represented.

Pollen Taxon	Percentage	Pollen Dispersal
Isoetes	+	NI
Lycopodium deuterodensum	+	U
L. scariosum	1.0	W
Gleichenia	14.0	U
Microstrobos	+	NI
Casuarina type	2.0	W
Chenopodiaceae	2.0	W
Compositae	20.0(3.0)	W
Donatia	2.0	SU
Epacridaceae T-type	9.0	SU
Leucopogon type	+	U
Monotoca	+	NI
Nothofagus fusca type	+	W
Eucalyptus	2.0	W
Melaleuca	+	W
Papilionaceae	+U	
Bellendena	+	NI
Orites	+	U
Coprosma	+	W
Rutaceae cf. *Phebalium*	+	NI
Cyperaceae	9.0	W
Drosera arcturi	+	NI
Gentianaceae cf. *Centaurium*	+	NI
Gentianella	+	NI
Goodeniaceae	+	W
Gramineae	17.0	W
Gunnera	+	SU
Astelia	+	NI
Lobeliaceae cf. *Lobelia*	+	NI
Plantago	+	U
Anemone	+	NI
Ranunculus	+	SU
Restionaceae	4.0	U
Scrophulariaceae cf.	+	NI
Umbelliferae Indet.	8.0	SU
Pollen sum:	64.8	

() refers to short echinate type probably extinct.

is an estimate of the pollen production/dispersal characteristics (=representivity) of the source plant(s) (cf. Macphail & McQueen 1983). All percentags are expressed relative to a pollen sum comprising the well-dispersed types (Macphail 1975).

Although the concentration of palynomorphs was low, 35 pollen types could be identified to a family or genus. The majority of these are herbs and, assuming the sources of the composite pollen were largely herbaceous, then herbs and pteridophytes constitute 70% of the pollen sum: Compositae (20%), Gramineae (17%), *Gleichenia* (14%), Cyperaceae plus Restionaceae (13%) and Umbelli-

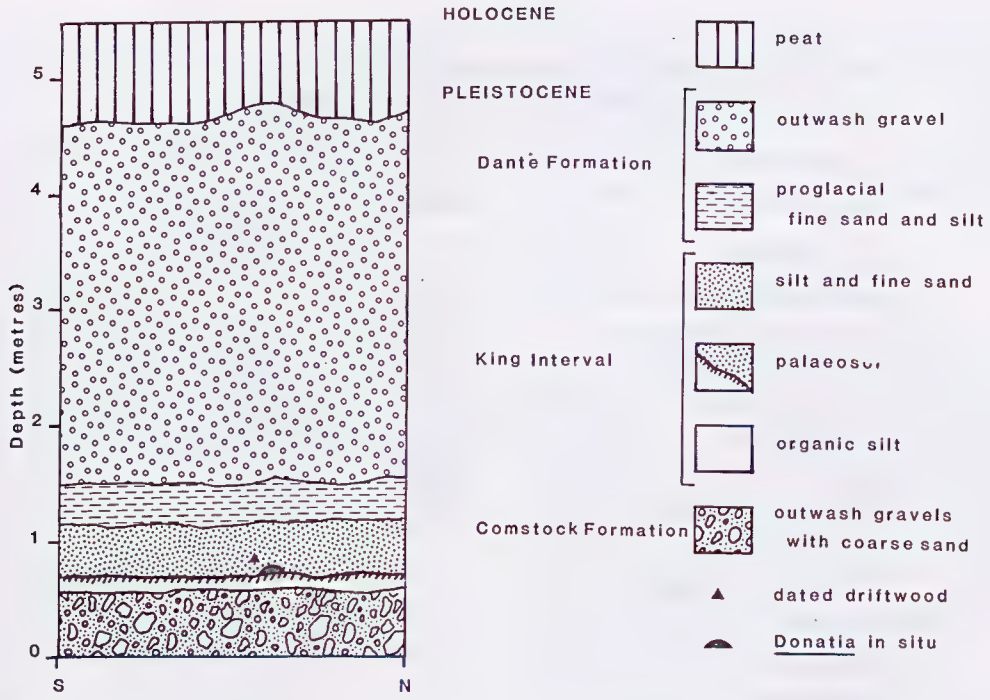

FIG.2 — Stratigraphy of section cut by the King River with locations.

ferae (8%). Woody types are comparatively infrequent with Epacridaceae (9%), *Eucalyptus*, *Casuarina* and *Donatia* (all 2%) being the most abundant. With the exception of *Microstrobos* and *Nothofagus gunnii* (*N. fusca* type), both of which have their main centres of distribution close to or above the timberline, pollen of rainforest taxa are absent. The 2% *Donatia* pollen is amongst the highest values of this type recorded to date in either fossil or modern assemblages in Tasmania (Macphail 1979, unpublished results, cf. fig. 3 in Colhoun 1985a).

Donatia Macrofossil

The photomicrographs of the cuticle and the electron micrographs of the leaf surface of the fossil are almost identical in detail with those of extant *Donatia novae-zelandiae* (plate 2), though somewhat smaller in size. Both show a distinctive raised cuticular ridge around the stomata. The leaf tips of both are bluntly acuminate. The typical dense tufts of axil hairs of *D. novae-zelandiae* are apparent in the cuticle preparations of the fossil.

Plate 3 (A to F) shows the distinctive patterns of surface cuticle, cell wall arrangement and gross stomatal size and pattern for the other three species of bolster plant. Electron micrographs of the leaf apices of these species also show distinctive differences.

Dracophyllum minimum is roughly triangular in cross-section near the leaf apex with each edge minutely serrate ending in an acute point. The stomata are very small, less than 15 μm long and epidermal cells have highly distinctive sinuous walls.

Phyllachne colensoi has an obtuse apex with a glandular pore just below it, on the abaxial surface (Curtis 1963). The cuticle is very thin and the electron micrograph shows evidence of localized collapse.

Abrotanella forsteroides has a distinctive acuminate often recurved hair-like apex with obscurely blunt serrulate leaf margins. Stomata are arranged in bands around the leaf converging toward the apex. The photomicrograph (plate 3F) of one of these bands shows the thickened walls of epidermal cells and the electron micrograph (plate 3E) shows imprints of stomata in cuticle from the closely appressed imbricate leaves.

DISCUSSION

The Comstock Glaciations are considered to predate the Last Glacial Stage on morphologic,

stratigraphic and weathering evidence at several sites in the central West Coast Range (table 2). The silts which unconformably overlie the Comstock gravels at this section have been only weakly modified by pedogenesis. The grey silt which overlies the palaeosol is interpreted as having been rapidly deposited in an aquatic environment. The upper silts represent renewed glacigenic sedimentation in a surface depression after a time break. The radiocarbon dates indicate that the Dante outwash gravels represent the late Last Glacial maximum (Kiernan 1980, 1983b).

Both the macrofossil and microfossil evidence suggest that a cold climate, species-rich herbfield bog mosaic occupied the site during the period represented by the organic silt. Rainforest was absent and sclerophyll trees rare within the region, with the latter possibly occurring in shrub form.

Although this interpretation is ecologically consistent with current reconstructions of full glacial climates in western Tasmania (Macphail 1975, Macphail & Colhoun 1985), caution is required for several reasons. Firstly, the pollen sample is an isolated one and possibly unrepresen-

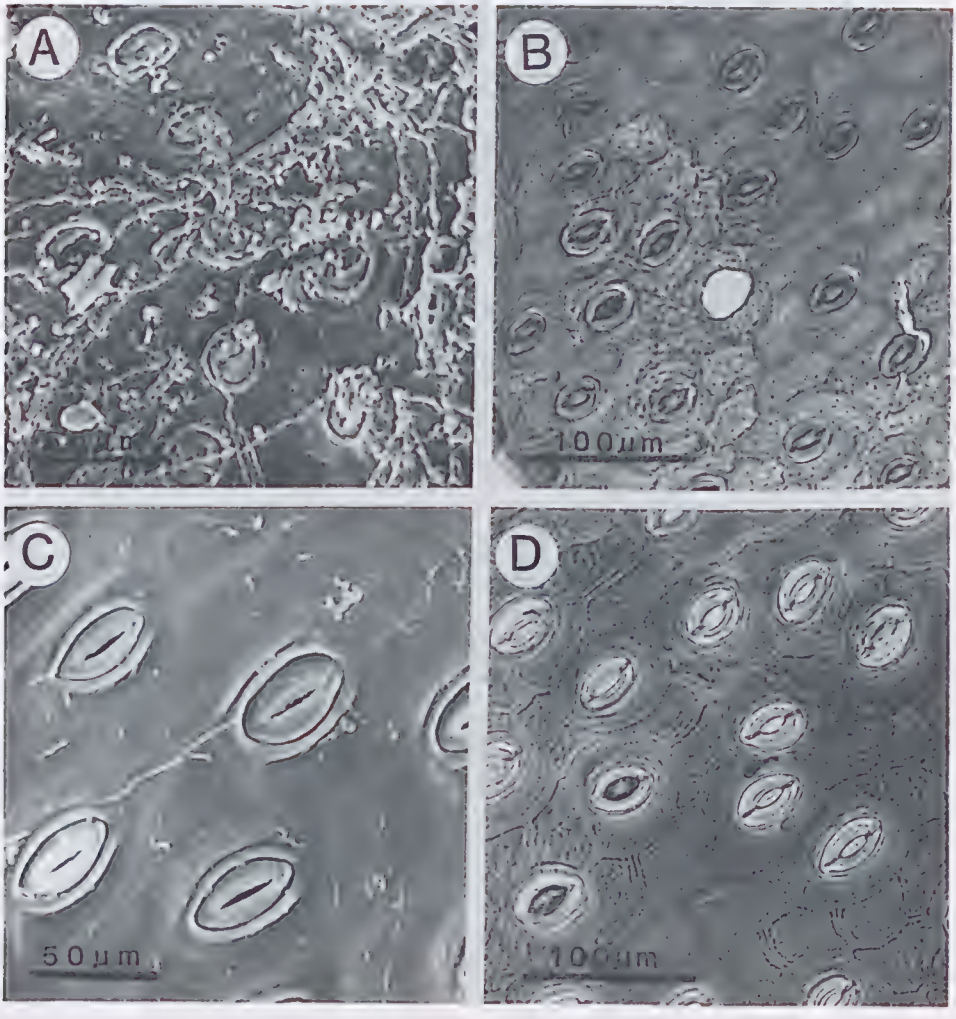

PLATE 2 — A, scanning electron micrograph of the fossil leaf surface; B, cuticular photomicrograph of the fossil showing guard cells and irregularly shaped epidermal cells; C, scanning electron micrograph of extant Donatia novae-zelandiae *leaf surface showing distinctive raised subsidiary cells; D, cuticular photomicrographs of extant* Donatia novae-zelandiae.

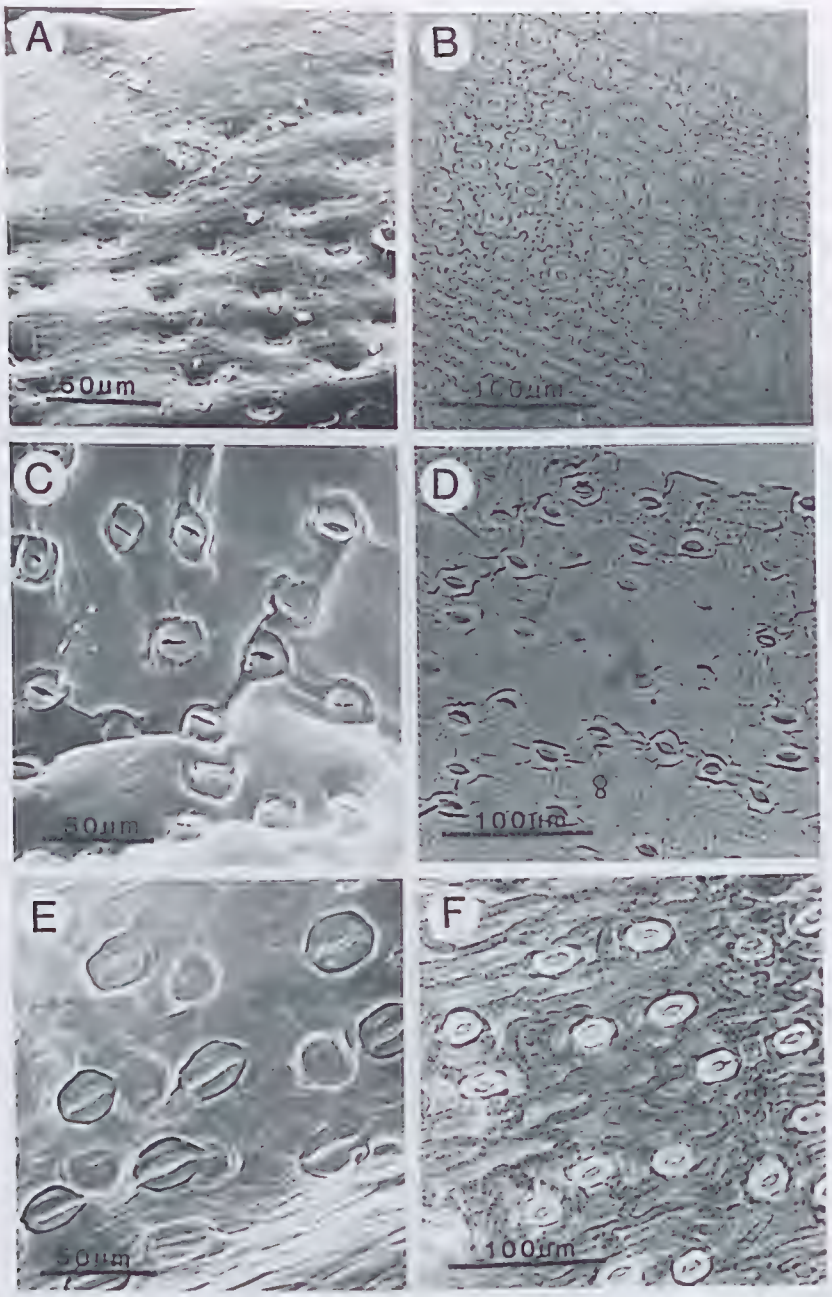

PLATE 3 — A, scanning electron micrograph of extant Dracophyllum minimum *showing small deep stomatal pits; B, cuticular photomicrograph of extant* Dracophyllum minimum *showing small stomata and highly distinctive sinuous epidermal cell walls; C, scanning electron micrograph of extant* Phyllachne colensoi *showing thin cuticle with some local collapse; D, cuticular photomicrograph of extant* Phyllachne colensoi *showing very thin nature of epidermal cell walls; E, scanning electron micrograph of one of the bands of stomata of extant* Abrotanella forsteroides *showing impressions of stomata from closely appressed leaves; F, cuticular photomicrograph of extant* Abrotanella forsteroides *showing distinctive stomatal band and highly thickened epidermal cell walls.*

TABLE 2

Nomenclature and probable correlation of glacial events in the West Coast Range.

	King Drainage System (Kiernan 1980, 1983a)	Henty Drainage System (Colhoun 1985b)	Pieman Drainage System (Sansom 1978, Augustinus 1982)
Last Late Glacial Stage	Dante Glaciation	Margaret Glaciation	Margaret Glaciation
Last Interglacial Stage			
Pre Last Interglacial Glacial Stage(s)	Comstock Glaciations	Henty Glaciation	Boco I & Boco II Glaciations
Late Pliocene/ Early Pleistocene Glacial Stage(s)	Linda Glaciations	Linda Glaciation	Bulgobac I & Bulgobac II Glaciations

tative. Secondly, *all* pollen assemblages are only a partial record of past floras with some indication of abundance (Macphail & McQueen 1983). Thirdly, either extremely rapid accumulation of sediments or in situ growth of a "strong" pollen source may result in the dilution of all or part of the pollen influx, particularly long distance transported types. Neither is considered likely given the high organic content of the silt and abundance of severely under-represented species such as *Donatia novae-zelandiae*, but such considerations are likely to be applicable to any palynofloras recovered from the overlying silts and sands.

The section therefore is interpreted as demonstrating the formation of a tundra soil during a period when the treeline lay below 230 m. *Donatia novae-zelandiae* can occasionally occur to low elevations in areas of reduced plant competition. In New Zealand it occurs at sea level in the far south, and in western Tasmania down to 80 m in the Harwood Valley (M.J. Brown, *pers. comm.* 1983), both in very acid peats. The pollen data strongly suggest a tundra vegetation rather than a valley bog.

Probably the strongest evidence that the reconstruction of the vegetation is correct comes from the close match between the Dante Rivulet assemblage and other near or full glacial period palynofloras recorded in lowland western Tasmania, notably those at Henty Bridge near Queenstown. There Colhoun (1985a) has recorded (subzone HB2, from the top of a unit of lacustrine clays and silts overlying glacial sediments) a Gramineae-Asteraceae-Restionaceae-Cyperaceae assemblage containing significant amounts of Epacridaceae, *Gleichenia* and *Lycopodium*. The major difference is that pollen of Cruciferae occurs in significant amounts whilst Umbelliferae are rare. As at Dante, sclerophyll tree pollen is relatively infrequent at Henty Bridge and rainforest tree pollen such as *Nothofagus cunninghami* virtually absent except in the highest sample (immediately underlying a weathered slope deposit). Colhoun dates this zone as 20–21 kyr b.p., based on a radiocarbon date of 23 640 b.p. from the underlying silts (samples of which contain between 5-10% *N. cunninghami* and 10-40% of *Microstrobos niphophilus* pollen).

Data from Kirkpatrick (1982) indicate that the present climatic treeline in this area of the West Coast lies at 975 m. The fossil *Donatia* and associated pollen evidence suggest minimum depression of the treeline by 750 m assuming this site was at or above the treeline. If the standard lapse rate of 0.6° C/100 m is assumed, this suggests that mean annual temperature was depressed by 4.5° C below its present value at this location at approximately 20 000 years B.P.

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We would like to thank Dr J.B. Kirkpatrick for his comments, Dr R.S. Hill for advice on cuticle preparation, Professor E.A. Colhoun for his advice in the field and Mr W. Jablonski for help with the electron microscopy. The radiocarbon dating was funded by the Geography Department, University of Tasmania.

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(accepted 28 November 1986)

THE VEGETATION OF THE GREAT NORTHERN PLAIN, NORTHEASTERN TASMANIA

by J.B. Kirkpatrick and J.M. Wells

(with two tables and four text-figures)

KIRKPATRICK, J.B. & WELLS, J.M., 1987 (30:vi): The vegetation of the Great Northern Plain, northeastern Tasmania. *Pap. Proc. R. Soc. Tasm.*, 121: 43-52. ISSN 0080-4703. Department of Geography, University of Tasmania, Hobart, Australia 7000; and National Parks and Wildlife Service, Sandy Bay, Tasmania 7005.

The Great Northern Plain is the last major remnant of the extensive inland heaths found in northeastern Tasmania in the early nineteenth century. A polythetic divisive classification of the vegetation of the plain and its environs, based on data from 131 quadrats, indicated that variation in structure, dominance and floristics was largely continuous, and that this variation was closely related to topographic position. A transect through the plain and adjacent woodland and forest showed that the position of the watertable in the soil and soil pH were independently strongly related to floristic and structural variation in the vegetation. Herbaceous exotic plant species have invaded parts of the plain, particularly in the areas near tracks. These exotic species do not present as severe a threat to the integrity of the area as *Phytophthora cinnamomi*, which had invaded to the south but which exhibits no symptoms on the plain itself.
Key Words: heath, TWINSPAN, Great Northern Plain, Tasmania.

INTRODUCTION

The Great Northern Plain is the major surviving remnant of the extensive inland treeless plains of northeastern Tasmania noted by George Augustus Robinson in the 1830's (Plomley 1966). Most of the clearing that is responsible for the relictual status of the Great Northern Plain has occurred since 1964 (Kirkpatrick 1977), and such clearing continues. There was a need for the collection of detailed information on the ecology of these inland plains, both as an end in itself, and as an historical record, in case clearing ever becomes complete. In this paper we present the results of a quantitative vegetation survey of the Great Northern Plain.

METHODS

Field Data Collection

Ninety-two quadrats were located in a stratifiedcrandom manner in the western part of the Great Northern Plain (fig. 1). This sampling was supplemented by 35 extra quadrats on a longer transect and 4 extra quadrats on a shorter transect (fig. 1) that were located to investigate the role of topography and watertable in differentiating communities. Additional quadrats were purposely placed in a nearby small plain and in an area that had been mined (fig. 1).

All observed vascular plant species were recorded in each 10 x 10 m quadrat, and notes were made of dominance in each stratum, and of the structure of each stratum following the scheme of Specht (1972). Slope and slope aspect were measured using a compass/clinometer and pH was measured using a CSIRO soil-testing kit. The field texture class of the surface soil was also recorded.

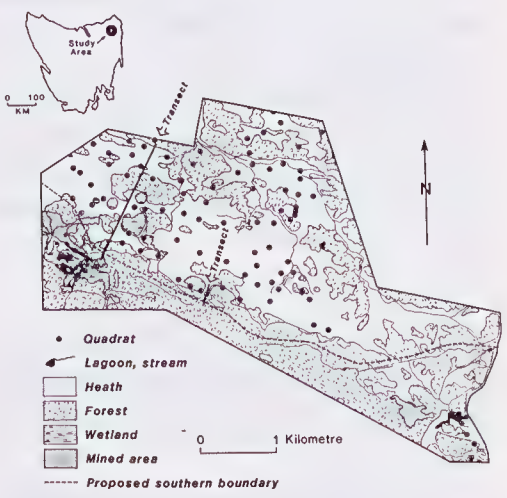

FIG. 1 — Vegetation map of Great Northern Plain study area, showing the transect locations, mined areas and the boundary recommended for listing in the Register of the National Estate.

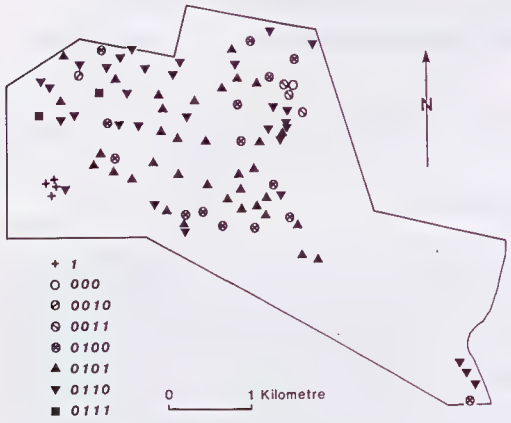

FIG. 2 — The distribution of the eight communities selected from the classificatory analysis of the Great Northern Plain data set.

In the case of the longer transect the texture and depth of all soil horizons were recorded as was the position of the watertable in mid-December 1985 after a week of heavy rain. Both transect lines were surveyed using a clinometer and tape. Watertable depths along the short transect line were recorded in August and mid-December 1985. All higher plant species observed in the study area were collected and pressed, a voucher collection being held in the Geography Department, University of Tasmania. Authorities for species nomenclature are given in the Appendix.

Numerical Analysis

The quadrat floristic data from the Great Northern Plain and adjacent vegetation were classified using the polythetic divisive computer programme TWINSPAN (Hill 1979). The eight-group level of division was used to describe the plant communities.

Data from the long transect were analysed using detrended correspondence analysis (Hill & Gauch 1980) and the relationship between the scores on the first two axes and environmental parameters was determined using Spearman's rank correlation coefficient (r).

RESULTS AND DISCUSSION

The Nature of the Plant Communities

The plant communities described below have been defined by their floristic composition rather than by structure and dominance. There is often a general coincidence between structural-dominance vegetation units and units defined by floristic composition. However, communities with heath as a dominant or subordinate stratum are usually very poorly differentiated if structure and dominance are used as the only criteria, because these attributes are highly dependent on the time elapsed since the last fire, and the past fire regime, in an environment where fire is a frequent event. In contrast, the time elapsed since the last fire has only a marginal effect on species composition, although an effect does exist (Russell & Parsons 1978).

The method used here to define the communities succeeds admirably in grouping like with like, but lacks clarity, there being few species or species combinations that can unambiguously be used to differentiate groups. This lack of clarity is largely a product of the general lack of sharp discontinuities in vegetation, the apparently sharp boundaries in the field usually being only the product of variation in abundance of one of the many species that compose the vegetation. Continuous variation means that the boundaries between plant communities can only be defined arbitrarily. Nevertheless, such arbitrary definition provides a useful framework for description, and this framework is most valuable when the internal homogeneity of groups is maximised.

As the variation between the groups is continuous and not necessarily closely related to structural variation, the vegetation map differentiates only previously mined areas, forest and woodland, heath and scrub, and wetland (fig. 1). These categories are partially transgressed by the classificatory groups (fig. 2, table 1), and are spatial generalizations of highly complex vegetation patterns (fig. 3).

The Plant Communities

The community codes denote the position of a group in the TWINSPAN classification. Thus, group 1 and all the groups starting with 0 are the result of the first division. Group 1 and 000 could not be further divided because of low numbers. All other groups are at the same level of division and thus are approximately equal in their variability.

Group 1

This community consists of four quadrats containing three distinct vegetation types, all occurring in the area affected by alluvial tin-mining (fig. 2). Three of the quadrats are dominated by herbs, grasses or graminoids, two being *Juncus-Holcus lanatus* sedgeland, and one being *Cyperus-Juncus* sedgeland. The fourth quadrat in the group

TABLE 1

Environmental characteristics, mean quadrat species richness, mean percentage of exotics in quadrats (E) and the percentage of quadrats with exotics (Ep) for the eight TWINSPAN groups from the Great Northern Plain.

Group	No. of quadrats	pH		Slope (°)		Vegetation			Species richness		E	Ep
		$\overline{X}$	σ_n	$\overline{X}$	σ_n	forest/ wood-land	heath/ scrub	sedge-land	$\overline{X}$	σ_n		
1	4	6.5	0.5	0.0	0.0	—	25	75	7.7	2.6	23.2	75
000	1	*	aquatic	**********					8.0	0.0	0.0	0
0010	4	4.9	0.5	0.1	0.1	—	—	100	16.7	3.9	3.2	50
0011	5	5.3	0.7	0.2	0.3	—	—	100	26.8	10.3	2.4	40
0100	15	5.2	0.6	0.4	0.7	—	27	73	33.4	8.9	3.4	47
0101	56	4.9	0.7	1.4	1.3	4	75	21	42.6	7.4	1.6	46
0110	40	4.9	0.8	1.4	1.0	40	60	—	37.7	9.9	1.9	38
0111	6	5.9	1.0	3.8	2.8	83	17	—	28.3	7.0	10.2	90

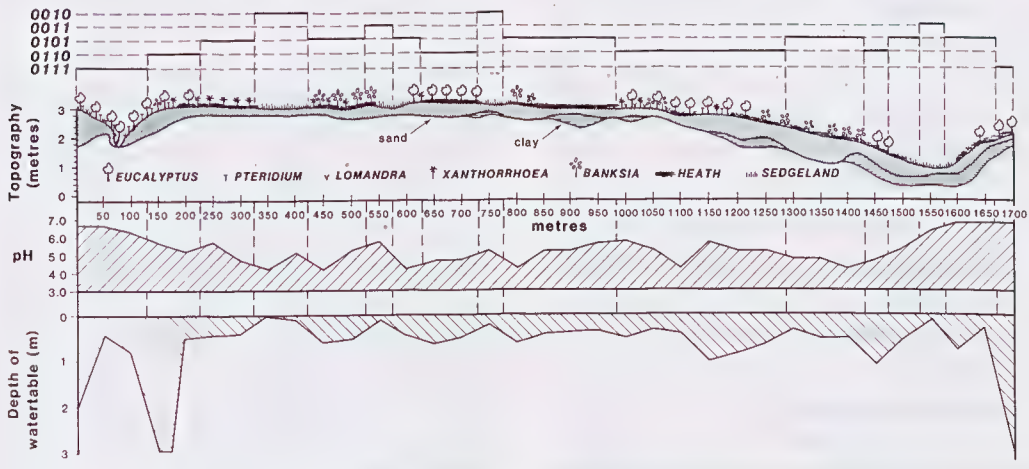

FIG. 3 — The long transect across the Great Northern Plain (fig. 1) showing structure and dominance of the vegetation, distribution of the floristic groups (selected from the classificatory analysis of the plain data set), soil characteristics, topography and watertable depth on 11 December 1985. The scale for topography is x10 the scale shown, which refers to the depth of soil horizons.

consists of *Leptospermum lanigerum* closed-scrub. Species richness is low (x = 7.75, σ_n = 2.28) and a considerable proportion of the biomass and species (x = 23.25%) are exotic, although the *Leptospermum lanigerum* closed-scrub quadrat is free of exotics. *Carex* spp., *Myosotis* spp., Juncus spp. and *Cyperus* spp. best characterize the group (table 2).

Group 000

This group consists of a single quadrat located in aquatic herbland dominated by *Triglochin procera* and *Potamogeton tricarinatus*. Six other species are recorded in the quadrat, none of which is exotic.

Group 0010

This group consists of four shallow wetland quadrats (fig. 2). The quadrats are all *Lepidosperma longitudinale* sedgeland. Half the quadrats in this group have no exotic species, the mean percentage of exotic species being only 3.25. Species richness is relatively low (x = 16.75, σ_n = 3.9). The species most characteristic of the group are *Brachycome cardiocarpa*, *Scirpus fluitans*, *Villarsia reniformis* and *Schoenus tesquorum*.

TABLE 2
The percentage frequencies of species by twinspan group.

Species that do not occur in more than three quarters of the quadrats in at least one group have been excluded. Exotic species are denoted with an asterisk.

Group	1	0010	0011	0100	0101	0110	0111
No. of quadrats	(4)	(4)	(5)	(15	(56)	(40)	(6)
Carex spp.	100	0	0	0	0	0	0
Myosotis sp.*	75	0	0	0	0	0	0
Cyperus sp.	75	0	0	0	2	0	0
Juncus spp.	75	0	60	27	0	2	33
Brachycome cardiocarpa	0	100	40	13	0	0	0
Scirpus fluitans	25	75	20	7	0	0	0
Lepidosperma longitudinale	0	100	80	93	79	62	66
Villarsia reniformis	0	75	40	27	7	0	0
Haloragis micrantha	0	75	100	87	89	32	0
Selaginella uliginosa	0	75	80	93	95	62	0
Schoenus tesquorum	0	75	40	13	2	0	0
Leptocarpus tenax	0	75	60	87	93	67	0
Melaleuca gibbosa	0	75	40	66	16	5	0
Drosera pygmaea	0	0	100	60	73	37	0
Calorophus lateriflorus	0	25	80	40	39	5	0
Schoenus apogon	0	25	80	87	48	25	33
Centella cordifolia	0	50	80	47	7	0	0
Boronia parviflora	0	0	0	80	68	10	0
Restio complanatus	0	0	20	73	84	40	0
Poa sp.	0	50	60	73	52	25	0
Schoenus tenuissimus	0	0	0	73	75	60	0
Haloragis tetragyna	0	25	0	13	100	90	17
Burchardia umbellata	0	0	0	47	95	82	17
Patersonia fragilis	0	0	0	60	95	52	17
Banksia marginata	0	0	40	66	95	87	83
Epacris lanuginosa	0	0	20	47	93	30	0
Lindsaya linearis	0	0	0	20	89	37	17
Tetrarrhena distichophylla	0	0	0	13	89	45	33
Leptospermum scoparium	0	0	0	60	84	85	17
Xanthorrhoea australis	0	0	0	0	77	80	33
Dillwynia glaberrima	0	0	0	0	75	70	0
Goodenia lanata	0	0	20	13	73	56	50
Lepidosperma filiforme	0	0	0	33	73	40	0
Lomandra longifolia	0	0	0	66	71	82	50
Epacris impressa	0	0	0	27	45	95	33
Eucalyptus amygdalina	0	0	0	0	21	90	83
Hypolaena fastigiata	0	0	0	7	45	75	17
Pteridium esculentum	0	0	0	7	0	52	100
Centaurium spp.*	0	0	0	20	4	15	83

Group 0011

This group also consists of shallow wetland quadrats, the quadrats in the group occurring in less frequently inundated areas than those in group 0010 (fig. 2). Four quadrats are *Lepidosperma longitudinale* sedgeland, one of these with sparse emergent *Melaleuca gibbosa* and *Leptospermum lanigerum*, and one quadrat is marginal herbland with no clear dominant. Three of the five quadrats have no exotic species, and the mean percentage of exotics is 2.42. Species richness is higher than that of group 0010 ($x = 26.8$, $\sigma_n = 10.3$). The species most characteristic of the group are *Drosera pygmaea*, *Empodisma minus* and *Centella cordifolia*.

Group 0100

This group largely consists of sedgeland (table 1). Dominance of the sedgeland is variably shared between *Lepidosperma longitudinale*, *Leptocarpus tenax* and *Lomandra longifolia* in six quadrats. *Lepidosperma longitudinale*, *Gahnia grandis* and *Gymnoschoenus sphaerocephalus* are singly dominant in two, two and one quadrats respectively. Three quadrats are open-heath, two dominated by *Melaleuca gibbosa* and *Casuarina*, and one dominated by *Leptospermum scoparium*. Closed-scrub dominated by *Melaleuca squarrosa*, with an understorey dominated by *Leptospermum longitudinale*, occupies one quadrat. The mean percentage of exotic species per quadrat is 3.4, the highest figure for the communities largely restricted to the plain (table 1). The mean species richness per quadrat is 33.4 (σ_n = 8.9). The group is best characterized by *Schoenus apogon*, *Boronia parviflora* and *Poa* spp. (table 2).

Group 0101

This group contains 56 quadrats, most of which are heath. Most of the quadrats have an emergent sparse to very sparse layer of tall shrubs to small trees, these almost totally consisting of *Banksia marginata*, *Eucalyptus amygdalina* and *E. ovata* in order of frequency. In order of frequency, the heath stratum is variably dominated or co-dominated by *Casuarina monilifera*, *Leptospermum scoparium*, *Banksia marginata*, *Xanthorrhoea australis* and *Sprengelia incarnata*. Other species that are commonly dominant or codominant in the taller strata are *Lomandra longifolia*, *Leptocarpus tenax*, *Lepidosperma longitudinale* and *Gymnoschoenus sphaerocephalus*, again in order of frequency. The mean percentage of exotic species per quadrat is the lowest for any of the terrestrial communities (x = 1.6). Species richness is the highest of any community (x = 42.6, σ_n = 7.4). The species that best discriminate this group are *Epacris lanuginosa*, *Lindsaya linearis* and *Tetrarrhena distichophylla*.

Group 0110

The quadrats in this group are almost equally divided between vegetation dominated by trees, and heath (table 1). The major dominants and codominants in the taller strata, in order of frequency, are *Eucalyptus amygdalina*, *Banksia marginata*, *Xanthorrhoea australis*, *Lomandra longifolia*, *Casuarina monilifera*, *Leptospermum scoparium*, *Gahnia grandis*, *Leptocarpus tenax*, *Pteridium esculentum*, *Epacris impressa* and *Dillwynia* spp. The mean quadrat species richness is 37.7 (σ_n = 9.9), with an average of 1.9% of the species in each quadrat being of exotic origin. Sixty-two percent of the quadrats contain no exotic species. The group is best characterized by *Epacris impressa*, *Eucalyptus amygdalina* and *Hypolaena fastigiata*.

Group 0111

This group of six forest and woodland quadrats consists of vegetation dominated by *Eucalyptus amygdalina* or *E. pauciflora*. The quadrats in the group are heavily invaded by exotic species, the mean percentage per quadrat being 10.2. Species richness is much lower than that found for the heath groups, the mean per quadrat being 28.3 (σ_n = 7.0).

Community Relationships

The communities characterized above form a continuum from sedgeland through heath to open-forest (table 1, fig. 3). This structural continuum parallels the floristic continuum. The vegetation dominated by trees falls almost totally within the sedgey *Eucalyptus amygdalina-E. pauciflora-E. ovata* woodland class of Duncan & Brown (1985). The Great Northern Plain also includes some small areas of grassy *E. ovata* woodland in which the ground stratum is dominated by *Themeda australis*. The heath contains five of the communities defined by Kirkpatrick (1977): *Sprengelia incarnata-Gymnoschoenus sphaerocephalus-Xyris* heath; *Boronia parviflora-Banksia marginata-Leptocarpus tenax* heath; *Gompholobium huegelii-Epacris lanuginosa* heath; *Bossiaea prostrata-Melaleuca gibbosa* heath; *Melaleuca squarrosa-Poa gunnii-Agrostis* heath. The wetland plant communities are widespread in the State, especially *Triglochin procera* aquatic sedgeland and *Lepidosperma longitudinale* sedgeland (Kirkpatrick & Harwood 1983). The arbitrary nature of classification within a continuum means that there is no necessary coincidence between groups defined in this study and those defined in others.

Environmental Relationships

The detrended correspondence analysis (DCA) of the floristic data from the long transect gave an eigenvalue for the first axis of 0.494, with the second axis scoring 0.292. The first axis proved to be strongly correlated with the depth of the watertable on 11 December 1985 ($r = 0.71$, $P < 0.001$) and less strongly correlated with slope ($r = 0.47$, $P < 0.01$). Table 2 also shows a general relationship between slope and plant communities, with the forest being on the steepest slopes and the

sedgeland on the gentlest. Slope in itself is ecologically meaningless, being, in this case, a partial surrogate of soil hydrological characteristics. It should also be noted that the depth of the watertable on one day cannot be expected to give a highly accurate measure of the ecologically relevant hydrological properties of the ecosystem, as the duration of water-logged conditions at various depths, and probabilities of moisture deficits occurring, are not necessarily closely related to any single measurement. For example, the precipitation that occurred immediately previously to the measurements would not have been fully distributed through the system on 11 December, and the soils would not have been at their maximum degree of watertable depth differentiation. Some data are available on the latter point. Watertable depths from the short transect at the end of winter 1985 were 0.43, 0.20, 0.13 and 0.25 m compared respectively with the December 11 measurements of 0.43, 0.33, 0.32 and 0.27 m.

FIG. 4 — The percentage of species of exotic origin by quadrat.

The second axis of the DCA of the long transect data is most closely related to pH ($r = 0.80$, $P < 0.001$), which in turn seems at least partially related to the presence of clay in the subsoil (fig. 3), and which is the best single surrogate for the complex of soil chemical conditions that constitutes fertility. The heath soils have generally lower pH values than either the wetland or woodland soils (table 1, fig. 3).

The structure and floristic composition of the vegetation of the plain suggests that much of the area could become Banksia or eucalypt woodland in the absence of firing. The frequency of firing has probably interacted with slow growth rates related to nutrient-poor and occasionally water-logged soils, such that tree species cannot achieve their height potential, being set back to ground level with each blaze. Tree seedling establishment after fire in the plain would be rendered difficult by competition from the rapidly resprouting heath and sedge species, which form a mat of rhizomes and other roots at the soil surface. This mat would provide strong competition for moisture during dry periods. During wet periods the destruction of the above-ground biomass by fire would eliminate transpiration losses, and thus increase the probabilities of seedlings being killed by water-logging. The fresh growth that follows firing attracts grazing animals that also present a hazard to small eucalypt seedlings. Nevertheless, the presence of fertile eucalypts, albeit as shrubs, throughout much of the heath indicates that establishment has occurred in the past, perhaps during a sequence of particularly favourable years. The relatively recent use of the plain by animals introduced from overseas, particularly by cattle, may reduce or preclude such regeneration in the future.

Management Problems

After land clearance and alluvial tin-mining, the major threat to the natural integrity of the vegetation of the Great Northern Plain is the invasion of exotic plant species, particularly the root rot fungus *Phytophthora cinnamomi*. Several herbaceous exotic higher plants, such as *Aira caryophyllea*, *Briza minor*, *Centaurium* spp., *Hypochaeris glabra* and *Leontodon leysseri*, have established themselves in parts of the plain, particularly in the vicinity of track access, and on the more fertile soils adjacent to cleared land (fig. 4). However, this opportunistic species assemblage is probably incapable of displacing the native vegetation without an enormous increase in soil fertility.

Although *Phytophthora cinnamomi* has become established along the access track to the Great Northern Plain in *Eucalyptus amygdalina* forest (C. Palzer, pers. comm.), there is no evidence of its presence on the plain itself. In fact, the almost ubiquitous abundance of epacrids, *Banksia* and *Xanthorrhoea* in the heath indicates its absence, or, at least, its very recent invasion. However, with infestations nearby there is a strong likelihood that the heath vegetation of the plain could be substantially modified by pathogen attack within the next century, the natural spread of the organism in the soil being a few metres per year across and upslope, but potentially much faster downslope.

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(accepted 2 February 1987)

APPENDIX

Native species observed in the Great Northern Plain study area.

Nomenclature generally follows Curtis (1963), Curtis (1967), Willis (1970) and Curtis & Morris (1975).

PTERIDOPHYTA

Adiantaceae
Adiantum aethiopicum L.

Dennstaedtiaceae
Pteridium esculentum (Forst.f.) Nakai

Gleicheniaceae
Gleichenia dicarpa R. Br.
G. microphylla R. Br.

Lindsayaceae
Lindsaya linearis Swartz

Selaginellaceae
Selaginella uliginosa (Labill.) Spring

Schizaeaceae
Schizaea bifida Willd.
S. fistulosa Labill.

MONOCOTYLEDONEAE

Centrolepidaceae
Centrolepis aristata (R. Br.) Roem. & Shult.
C. fascicularis Labill.
C. strigosa (R. Br.) Roem. & Shult.

Cyperaceae
Baumea acuta (Labill.) Palla
B. arthrophylla (Nees) Boeck
B. tetragona (Labill.) S.T.Blake
Chorizandra cymbarica R. Br.
Cyperus sp.
Eleocharis sphacelata R. Br.
Gahnia grandis (Labill.) S.T.Blake
Gymnoschoenus sphaerocephalus (R. Br.) Hook. f.
Lepidosperma concavum R. Br.
L. filiforme Labill.
L. laterale R. Br.
L. longitudinale Labill.
Schoenus apogon Roem. & Schult.
S. maschalinus Roem. & Schult.
S. tenuissimus Benth.
Scirpus fluitans Hook. f.
S. inundatus (R. Br.) Poir.
S. sp.

Hypoxidaceae
Hypoxis hygrometrica Labill.

Iridaceae
Diplarrena moraea Labill.
Patersonia fragilis (Labill.) Druce
P. longiscapa Sweet

Juncaceae
Juncus sp.
J. bufonius L.
J. pallidus R. Br.
Luzula sp.

Juncaginaceae
Triglochin procera R. Br.
T. striata Ruiz. & Pav.

Liliaceae
Anguillaria dioica R. Br.
Arthropodium milleflorum (DC.) Macbride
Burchardia umbellata R. Br.
Caesia parviflora R. Br.
Chamaescilla corymbosa (R. Br.) F.Muell. ex Bent
Dianella revoluta R. Br.
Dichopogon strictus (R. Br.) J.G. Baker
Laxmannia sessiliflora Decaisne
Lomandra longifolia Labill.
Stypandra caespitosa R. Br.
Tricoryne elatior R. Br.
Xanthorrhoea australis R. Br.

Orchidaceae
Acianthus sp.
Caladenia catenata (Sm.) Druce
C. dilata R. Br.
Cryptostylis subulata (Labill.) Reichenb. f.
Diuris sulphurea R. Br.
Gastrodia sesamoides R. Br.
Microtis atrata Lindl.
M. biloba W.H. Nicholls
M. orbicularis R.S. Rogers
M. unifolia (Forst. f.) Reichenb. f.
Prasophyllum gracile R.S. Rogers
P. rogersii H.M.R. Rupp
P. uroglossum H.M.R. Rupp
Pterostylis barbata Lindl.
P. nana R. Br.
Thelymitra media R. Br.

Poaceae
Agrostis avenacea J.F. Gmel.
A. venusta Trin.
Amphibromus recurvatus J.R. Swallen
Danthonia caespitosa Gaudich
D. laevis J.W. Vickery
D. pilosa R. Br.
D. semiannularis (Labill.) R. Br.
D. setacea R. Br.
Deschampsia caespitosa (L.) Pal. Beauv.

Deyeuxia quadriseta (Labill.) Benth.
Dichelachne crinata (L. f.) Hook. f.
D. rara (R. Br.) Vickery
Microlaena stipoides (Labill.) R. Br.
Pentapogon quadrifidus (Labill.) Baill.
Poa L.
Stipa mollis R. Br.
S. pubinodis Trin. et Rupr.
. semibarbata R. Br.
Tetrarrhena acuminata R. Br.
T. distichophylla (Labill.) R. Br.
Themeda australis (R. Br.) Stapf.

Potamogetonaceae
Potamogeton tricarinatus F. Muell. et A. Bennet

Restionaceae
Calorophus lateriflorus (R. Br.) F. Muell.
Hypolaena fastigiata R. Br.
Leptocarpus tenax (Labill.) R. Br.
Restio australis R. Br.
R. complanatus R. Br.

Xyridaceae
Xyris gracilis R. Br.
X. marginata Rendle Endemic
X. operculata Labill.

DICOTYLEDONEAE

Apiaceae
Centella cordifolia (Hook. f.) Nannf.
Hydrocotyle capillaris F. Muell.
H. javanica Thunb.
H. muscosa R. Br.
H. sibthorpioides Lamk.
Xanthosia dissecta Hook. f.
X. pilosa Rudge
X. pusilla Bunge
X. tridentata DC.

Asteraceae
Brachycome cardiocarpa F. Muell. ex Benth.
Cotula reptans Benth.
Craspedia glauca (Labill.) Spreng.
Gnaphalium japonicum Thunb.
Helichrysum bicolor Lindl.
H. dealbatum Labill.
H. scorpioides Labill.
Lagenophora stipitata (Labill.) Druce
Leptorhynchos squamatus (Labill.) Less.
Microseris scapigera (Sol. ex A. Cunn.) Schult. Bip.
Senecio hispidulus A. Rich

Baueraceae
Bauera rubioides Andr.

Campanulaceae
Wahlenbergia consimilis N. Lothian
W. gracilenta N. Lothian
W. gymnoclada N. Lothian
W. quadrifida (R. Br.) A. DC.
W. tadgellii N. Lothian

Casuarinaceae
Casuarina littoralis Salisb.
C. monilifera L. Johnson
C. paludosa Sieb. ex Spreng.
C. stricta Ait.

Dilleniaceae
Hibbertia acicularis (Labill.) F. Muell.
H. empetrifolia (DC.) Hoogl.
H. procumbens (Labill.) DC.
H. riparia (R. Br. ex DC.) Hoogl.

Droseraceae
Drosera auriculata Backh. ex Planch.
D. binata Labill.
D. gracilis Hook. f. ex Planch.
D. peltata Sm. ex Willd.
D. planchonii Hook. f.
D. pygmaea DC.

Epacridaceae
Acrotriche serrulata (Labill.) R. Br.
Astroloma humifusum (Cav.) R. Br.
A. pinifolium (R. Br.) Benth.
Brachyloma ciliatum (R. Br.) Benth.
Epacris impressa Labill.
E. lanuginosa Labill.
E. obtusifolia Sm.
Leucopogon collinus (Labill.) R. Br.
L. ericoides (Sm.) R. Br.
L. virgatus (Labill.) R. Br.
Lissanthe strigosa (Sm.) R. Br.
Sprengelia incarnata Sm.
Styphelia adscendens R. Br.

Euphorbiaceae
Amperea xiphoclada (Sieb. ex Spreng.) Druce
Poranthera microphylla Brogn.

Fabaceae
Bossiaea cinerea R. Br. ex Ait. f.
B. prostrata R. Br.
Dillwynia glaberrima Sm.
D. sericea A. Cunn.
Kennedia prostrata R. Br. ex Ait. f.
Gompholobium huegelii Benth.
Hovea heterophylla A. Cunn. ex Hook. f.
Platylobium formosum Sm.
P. obtusangulum Hook.
P. triangulare R. Br. ex Ait. f.

Pultenaea dentata Labill.
P. juniperina Labill.
Sphaerolobium vimineum Sm.

Gentianaceae
Villarsia reniformis R. Br.

Goodeniaceae *Dampiera stricta* (Sm.) R. Br.
Goodenia humilis R. Br.
G. lanata R. Br.
Scaevola hookeri (de Vriese) Hook. f.
Selliera radicans Cav.

Haloragaceae
Haloragis micrantha (Thunb.) R. Br. ex Sieb. & Zucc.
H. tetragyna (Labill.) Hook. f.
H. teucrioides (DC.) Schlechtendal
Myriophyllum pedunculatum Hook. f.
M. propinquum A. Cunn.

Hypericaceae
Hypericum gramineum Forst. f.
H. japonicum Thunb.

Lauraceae
Cassytha glabella R. Br.

Lentibulariaceae
Utricularia dichotoma Labill.
U. lateriflora R. Br.

Lobeliaceae
Lobelia alata Labill.
Pratia pedunculata R. Br.

Loganiaceae
Mitrasacme paradoxa R. Br.
M. pilosa Labill.
M. serpyllifolia R. Br.

Mimosaceae
Acacia genistifolia Link.
A. melanoxylon R. Br.
A. mucronata Willd. ex H. Wendl.
A. myrtifolia (Sm.) Willd.
A. sophorae (Labill.) R. Br. ex Ait.
A. ulicifolia (Salisb.) Court
A. verticillata (L'Herit.)

Myrtaceae
Baeckea ramosissima A. Cunn.
Eucalyptus amygdalina Labill. Endemic
E. ovata Labill.
E. pauciflora Sieb. ex Spreng.
Kunzea ambigua (Sm.) Druce
Leptospermum glaucescens S. SchauerEndemic
L. lanigerum (Ait.) Sm.
L. scoparium J.R. & G. Forst.
Melaleuca ericifolia Sm.
M. gibbosa Labill.
M. squamea Labill.
M. squarrosa Donn ex Sm.

Oxalidaceae
Oxalis corniculata L.

Pittosporaceae
Marianthus procumbens (Hook.) Benth.

Plantaginaceae
Plantago debilis R. Br.
P. varia R. Br.

Polygalaceae
Comesperma calymega Labill.
C. volubile Labill.

Proteaceae
Banksia marginata Cav.
Hakea teretifolia (Salisb.) J. Britt.
Lomatia tinctoria R. Br. Endemic
Persoonia juniperina Labill.

Rhamnaceae
Pomaderris apetala Labill.
P. elliptica Labill. Endemic

Rosaceae
Acaena echinata Nees
A. novae-zelandiae Kirk

Rubiaceae
Asperula gunnii Hook. f.
Opercularia varia Hook. f.

Rutaceae
Boronia nana Hook.
B. parviflora Sm.
B. pilosa Labill.

Santalaceae
Exocarpos cupressiformis Labill.
Leptomeria drupacea (Labill.) Druce

Scrophulariaceae
Gratiola latifolia R. Br.
G. nana Benth.

Stylidiaceae
Stylidium perpusillum Hook. f.
S. graminifolium Swartz

Thymelaeaceae
Pimelea humilis R. Br.
P. linifolia Sm.

Violaceae
Viola betonicifolia Sm.
V. hederacea Labill.
V. sieberana Spreng.

HELICHRYSUM PUMILUM VAR. *SPATHULATUM* (COMPOSITAE: INULEAE), NEW FROM TASMANIA

by A.M. Buchanan

(with two text-figures)

BUCHANAN, A.M., 1987 (30:vi): *Helichrysum pumilum* var. *spathulatum* (Compositae: Inuleae), new from Tasmania. *Pap. Proc. R. Soc. Tasm*, 121: 53-56. ISSN 0080-4703. Tasmanian Herbarium, G.P.O. Box 252C, Hobart, Tasmania.

A name is provided for the spathulate-leaved variant of *Helichrysum pumilum*. Comments are made on the collecting activities of Ronald Gunn and Joseph Milligan.

Key Words: *Helichrysum*, Compositae, Milligan, Gunn, Tasmania.

INTRODUCTION

J.D. Hooker (1856) in his original description of *Helichrysum pumilum* noted the existence of a broader-leaved form which he designated var. *β*. Subsequent authors (Bentham 1867, Rodway 1903, Curtis 1963) have ignored this variant and included both spathulate-and linear-leaved forms in a single taxon. For some time, workers in the field have recognised the distinctiveness of the spathulate-leaved variant and its preference for exposed situations on mountain slopes and summits in skeletal soils. A close examination of herbarium material and comparative studies in the field have convinced the present author of the necessity of formally recognising these plants as distinct at the varietal level.

DESCRIPTION

Helichrysum pumilum J.D. Hook., Fl. Tasm. 1(1856) 213-4.

[Typus: 'Gunn, 2045'; *holotypus*: Gunn 2045 Heathy and peaty ground, Macquarie Harbour, 8.10.[18]46, K (Herbarium Hookerianum) n.v. (photograph!). *Isotypus*: *J. Milligan 756*, Heathy and Peaty ground Macquarie Harb. 8.10.[18]46 HO 12436!, N.S.W. *Probable Isotypus*: *J. Milligan 756*, Peaty flats, terrace grounds between mouth of Gordon River and Birchs Inlet, Macquarie Harbour, 8.x.1846, HO 12435!]: Benth., Fl. Aust. 3 (1867) 619-620; Johnston, Field Memoranda Tasm. Bot. (1874) 24; Spicer, Hdbk Pls Tasm. (1878) 118; Rodway, Tasm. Fl. (1903) 86;Curtis, Stud. Fl. Tasm. 2(1963) 330;Curtis in Stones & Curtis, The Endemic Fl. of Tasm. 9(1967) 48; Cameron (ed.), Guide Fls and Pls Tasm. (1981) 32.

Perennial herb, gynodioecious, low tufted, with erect or horizontal rhizome to 2 mm diam., roots coarse. *Leaves* radical, basally sheathing, linear to spathulate (8)15-50 mm in length and 1-5 mm in breadth, woolly beneath. *Capitulum* solitary on slender, erect, white tomentose, bracteate scape 20-100 mm in length. *Involucre* 15-20 mm diam., outer phyllaries 5-8 mm in length, white, streaked with brown or pink, inner phyllaries to 10 mm in length, white or pink, elliptical, semi-spreading, basal region thickened, brown. *Florets* of two types on separate plants; female *filiform florets*, 20-60 per capitulum, corolla tube 2.5-3.5 mm in length, 0.4 mm in diameter, pink to purple, lobes usually 5, sometimes unequal in size, c.0.5 mm in length, style deeply bifid, arms exserted, achenes 1.0–1.5 mm in length, hirsute; bisexual *disc florets*, 20-40 per capitulum, corolla tube 2.5-3.0 mm in length, 0.6-0.8 mm in diameter, pink to purple, lobes 5, 0.5-0.7 mm in length, with tufts of simple multicellular, uniseriate hairs, stamens with filaments adnate to lower one-third of corolla tube, anthers 5, 1.7 mm in length, style shortly bifid, not or only slightly exserted, achenes 0.5-1.0 mm in length, sparsely hairy, pappus bristles papillose, clavellate, slightly exceeding the floret.

Endemic in Tasmania where it is confined to the west and the south of the island.

Flowering December to February.

Note

In his original description J.D. Hooker (1860) cites "Gunn 2045" as the type and the type sheet at Kew bears the following information in Gunn's handwriting, "Heathy and peaty ground Macquarie

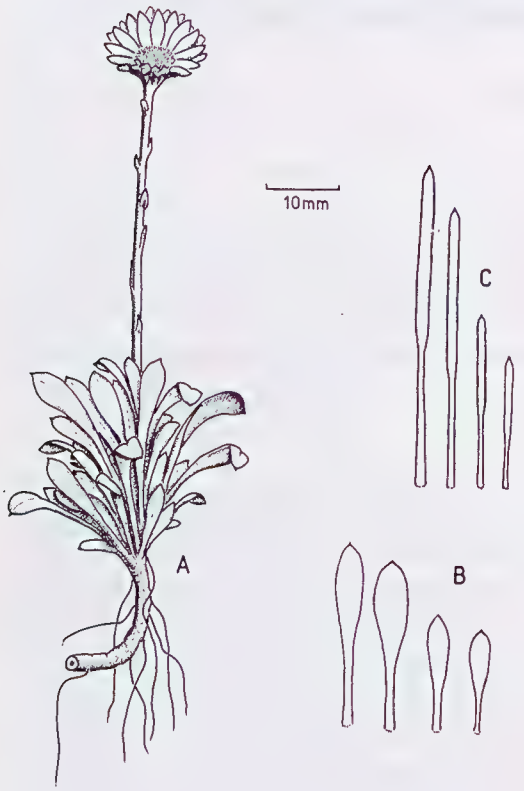

FIG. 1 — Helichrysum pumilum. *A. var.* spathulatum, *habit. B. var.* spathulatum, *range of leaf shape. C. var.* pumilum, *range of leaf shape. (A,B from Moscal 9280, C from Buchanan 1331).*

Harbour 8.10.46." It should be noted that 2045 is Gunn's species number for *Helichrysum pumilum* and not a collecting number. At HO there is a sheet labelled "Heathy and Peaty ground Macquarie Harb. 8.10.46 JM 756" in Joseph Milligan's handwriting which matches the type material very well. A second sheet is labelled "756 Peaty flats — Terrace grounds between mouth of Gordon River and Birches Inlet McQuie Hbr. 8.10.46" also in Milligan's handwriting. Gunn is not known to have been in the Macquarie Harbour area in 1846. A survey of Gunn's and Milligan's collections at HO shows that Gunn was in that area on only one occasion, during February 1845, which agrees with the account given by Burns & Skemp (1961) of his activities. Milligan on the other hand collected widely in the Macquarie Harbour area from July 1846 to March 1847.

It is evident that this is a further case of Gunn having forwarded another collector's material to Kew without acknowledging its source, a problem already observed by Haegi (1982) and Short (1986).

Helichrysum pumilum J.D. Hook. var. *pumilum*

Leaves linear, 20-50 mm in length and 1-2 mm in breadth; lamina with margins revolute, apex acute to sub-acute, mucronate; upper surface green, glabrous, or with a very fine deciduous felt, under surface white woolly. *Scape* 20-100 mm in length, bracts linear, leaf-like (fig. 1C).

Western and southern Tasmania from Nelson Bay River in the north to the wet heathlands of the south coast in the south and as far east as Innes Falls, Mt Mawson and Esperance Peak (fig. 2A).

Illustration

J.D. Hook., Flora Tasmaniae (1856) pl.LX.

Helichrysum pumilum J.D. Hook. var. *spathulatum* A.M. Buchanan, var. nov.

Helichrysum pumilum var. *β* J.D. Hook. Fl. Tasm. 1 (1860) 213.

Differt a varietate typica foliis spathulatis (8)15-25(28) mm longis, 2-5 mm latis, cinereocoactis, sub-planis; apicibus recurvis, mucronatis; bracteis inferis foliiformis, bracteis superioribus scariosis.

Typus: *A. Moscal 9202*, Jubilee Range, 8.i.1985. *Holotypus*: HO 97029

Leaves crowded in a rosette, spathulate (8)15-25(28) mm in length and 2-5 mm in breadth at the widest point; lamina flat to slightly channeled along midrib, apex recurved, rounded mucronate; both surfaces covered with a felted mat of hairs, grey above and light grey densely woolly beneath. *Scape* 20-60 mm in length, lower bracts leaf-like, upper bracts scarious, resembling the outer phyllaries (fig. 1A,B).

Confined to mountains of the central west of Tasmania (fig. 2B).

Illustration

Stones *in* Stones & Curtis, The Endemic Flora of Tasmania 1(1967) pl.21 as *Helichrysum pumilum*.

Note

J.D. Hooker described var. *β* from a Milligan collection which is now in the Herbarium Hookerianum at Kew, bearing the labels "Tasmania Dr. Milligan" "*Helichrysum pumilum* Hf *β*". In his

protologue Hooker cites the locality for this collection as "Macquarrie Harbour". Milligan probably collected this specimen during his ascent of Mt Sorell near the eastern shore of Macquarie Harbour. The holotype of var. *spathulatum* closely resembles Milligan's collection, of which there is a photograph at HO.

SPECIMENS EXAMINED (ALL TASMANIAN)

Helichrysum pumilum var. *pumilum*

Adams 39, Moores Garden, 14.i.1984 (HO 76662). — *Berrigan s.n.*, Frenchmans Cap, near summit, -.iv.1978 (HO 28644). — *Boyer s.n.*, Mt Mawson Plateau, 21.xii.1980 (HO 37369). -*Buchanan 1331*, Birchs Inlet, 15.xi.1983 (HO 72953). — *Buchanan 3429*, Heath between west end of Turua Beach and the shelter, 26.iv.1984 (HO 76586). — *Buchanan 7745*, South side of Giblin River, c. 2 km from mouth, 10.i.1986 (HO 97701). — *Buchanan 8125*, Summit of the Lawson Range, 25.i.1986 (HO 98431). — *Buchanan 8808*, Burke Creek flats, Cox Bight, 9.viii.1986 (HO 98908). — *Collier 1996*, Western Arthur Range, 5.xii.1986 (HO 101379). — *Comber 2159*, Mt Sedgwick 2000 ft, 28.ii.1930 (HO 98001). — *Curtis s.n.*, Tarn Shelf, National Park, 3,i.1948 (HO 52537). — *Davis 1362*, Melaleuca Settlement, Moth Creek, s.d. (HO 12433). — *Giblin s.n.*, Jubilee Range, -.i.1929 (HO 12430). — *Jarman 31*, Scotts Peak Road near Clear Creek, 31.x.1979 (HO 31389). — *Milligan 756*, Macquarie Harbour, 8.x.1846 (HO 12436). — *Milligan 756*, Between mouth of Gordon River and Birchs Inlet, Macquarie Harbour, 8.x.1846 (HO 12475). — *Moscal 1826*, Rocky Hill, 15,ii,1983 (HO 92261). — *Moscal 2010*, Innes Falls, 27,ii,1983 (HO 92564). — *Moscal 2118*, 2 km SE of Federation Peak, 9.iii.1983 (HO 71623). — *Moscal 5716*, Point Hibbs, 17,i,1984 (HO 74419). — *Rodway s.n.*, Mt Dundas, -.xii.1893 (HO 12427). *Rodway s.n.*, Esperance Peak, -.xii,1894 (HO 12434).

Helichrysum pumilum var. *spathulatum*

Buchanan 5289, Jubilee Range, 13,i,1985 (HO 98903). — *Collier 1995*, Western Arthur Range, 5.xii.1986 (HO 101380). — *Elliott s.n.*, Denison River, 6.i.1947 (HO 52621). — *Gordon s.n.*, N. Col, Frenchmans Cap, 13.xii.1944 (HO 52538). —*Harwood s.n.*, Denison Range, Reeds Peak area, xii.1978 (HO 29563). — *Jarman s.n.*, Double Peak, 10,xii,1978 (HO 30354). — *Macphail s.n.*, Tyndall Range between Mts Tyndall and Geikie, 8.xii.1980 (HO 37071). — *Moscal 1930*, Mt Inglis — Fury Gorge, 25.ii.1983 (HO 92416). — *Moscal 2011*, Little Plateau, Cradle Mtn, 28.ii.1983 (HO 92565). — *Moscal 9202*, Jubilee Range, 8.i.1985 (HO 97029), Holotype.

FIG. 2 — Geographic range of Helichrysum pumilum *in Tasmania. A. var.* pumilum. *B. var.* spathulatum.

SEX EXPRESSION

Capitula of both varieties of *Helichrysum pumilum* are of two types:

a. Hermaphrodite, bearing bisexual disc florets, and

b. Female, bearing filiform (pistillate) florets.

A very low degree of inconstancy (about 3%) was noted in the specimens examined, with an occasional hermaphrodite capitula containing one or two female florets, e.g. *Moscal 9280*. In the populations of *H. pumilum* var. *pumilum* examined, female plants and bisexual plants occurred in more or less equal numbers and their capitula contained 20-30 florets. Within the limited number of var. *spathulatum* specimens available, a tendency towards a slightly higher frequency of bisexual plants and a greater number of florets per capitulum compared with the type variety was observed. Further insight could undoubtedly be obtained from detailed population studies in which correlations may become evident between sex distribution and ecological gradients. In other genera of Compositae sex ratios and hence plant breeding systems have proved to be valuable aids in taxonomic studies of the groups concerned (e.g. Lloyd 1972a,b, Short 1981).

DISCUSSION

Helichrysum pumilum as a species does not closely resemble any other taxon in the genus, although the habit of var. *spathulatum* approaches

that of *H. milliganii*, another Tasmanian endemic. Typical plants of var. *spathulatum* can be readily distinguished from var. *pumilum* by their relatively shorter, recurved, matt grey spathulate leaves. The matt grey colouration is imparted by a well-felted layer of grey hairs which occasionally in leaves long exposed to the elements, weathers off in a thin sheet. The apices of the leaves are flattened and recurved so as to be in extreme cases almost appressed to the ground in contrast with the erect or semi-spreading leaves of var. *pumilum*. The mid to upper bracts of the scape of the type variety are always linear and leaf-like whereas the upper bracts, at least, of var. *spathulatum* are expanded into a broad scarious margin. A few plants are encountered which are more or less intermediate in one or other character but these can usually be determined by reference to the leaf length/breadth ratio. The type variety is almost invariably confined to wet soils of deep acidic peat, usually developed on quartzite, where the large cyperaceous tussock *Gymnoschoenus sphaerocephalus* is dominant, a habitat commonly referred to as "buttongrass plains". Occasionally it extends into the sub-alpine zone in peaty soils developed on quartzite, dolerite or mudstone, especially at the southeastern limits of its range. The variety spathulatum on the other hand is confined to the upper slopes or summits of mountains, often in very shallow skeletal soils or even in crevices of quartzite rock outcrops.

ACKNOWLEDGEMENTS

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(accepted 3 March 1987)

TYPE LOCALITIES FOR SIX SPECIES OF TASMANIAN LAND MOLLUSCS (PULMONATA:STYLOMMATOPHORA)

by Ron C. Kershaw

KERSHAW, R.C., 1987 (30:vi): Type localities for six species of land molluscs (Pulmonata: Stylommatophora). *Pap. Proc. R. Soc. Tasm.*, 121: 57–68. ISSN 0080-4703. Queen Victoria Museum, Wellington Street, Launceston 7250.

Type localities are determined and described for the mollusc species *Caryodes dufresnii* (Leach 1815), *Anoglypta launcestonensis* (Reeve 1853), family Caryodidae; *Bothriembryon tasmanicus* (Pfeiffer 1853) and *B. brachysoma* Pilsbry 1900, family Bulimulidae; and *Cystopelta petterdi* Tate 1881 and *C. bicolor* Petterd & Hedley 1909, family Cystopeltidae from Tasmania. The determinations are supported by historical data.
Key Words: Tasmania, land molluscs, type localities, habitat.

INTRODUCTION

Study of the variation in several genera of land molluscs living in Tasmania suggests a relationship between the environment and snail morphs. In the process of distinguishing between mollusc species and varieties, it is essential to determine the types and type localities of the known taxa.

The aim of this paper is to determine or clarify and describe the type localities for species of the genera *Caryodes*, *Anoglypta*, *Bothriembryon* and *Cystopelta*. The types of the species *Caryodes dufresnii* (Leach 1815), *Bothriembryon tasmanicus* (Pfeiffer 1853), *Cystopelta petterdi* Tate 1881 and *C. bicolor* Petterd & Hedley 1909 are unknown or have been lost. Descriptions of neotypes and voucher specimens will be presented elsewhere (Kershaw 1987, and in prep.).

The type localities for *Cystopelta petterdi* and *C. bicolor* are known approximately. The determinations here are concerned with neotype localities. The type locality of *C. petterdi* is now occupied by urban development. Those of *Caryodes dufresnii*, *Anoglypta launcestonensis*, *Bothriembryon tasmanicus* and *B. brachysoma* have not previously been accurately determined.

METHODS

The determinations here suggested are made on the basis of the criteria provided for in Recommendation 72H of the International Code of Zoological Nomenclature, Third Edition, 1985. Museums in Europe and America which may have held original material have been consulted. The original descriptions together with labels with possible original material where available, have provided valuable data.

Some localities are suggested by Iredale (1937a, 1937b) and Hedley (1891). The determinations and the habitat data are supported by fieldwork throughout Tasmania except for South Cape Bay and Maria Island. Information in these cases has come from other people and the literature. Recognition of vegetation types is based on the work of Jarman & Brown (1983, rainforest), Gilbert (1959, mixed forest), Jackson (1974, wet sclerophyll) and Duncan & Brown (1985, dry sclerophyll). Climatic data are presented in Appendix 1. Map references are based on the Topographical Survey of Tasmania, 1:100 000 series.

CARYODES DUFRESNII (LEACH, 1815)

Proposed Type Locality: Near South Cape Bay, southern Tasmania.

This species was described by Leach (1815) as *Bulimus dufresnii*, the brief description supplemented by a readily recognizable figure. The locality given by Leach was "Australasia" but the author also stated "Inhabits New Holland. The shell was named after M. Dufresne "in whose collection ... it occurs." Because of the name, consideration has been given to the expedition under the command of Captain Marion du Fresne in 1772 as the occasion of collection of the shell. This possibility and the distribution of shell forms led Kershaw & Dartnall (1972) to consider south-eastern Tasmania as a possible type locality.

Original Material

Leach (1815) clearly established that the shell described came from the collection of Louis Du

Fresne. The history of this collection, which is partly lodged in Edinburgh and partly within the Delessert Collection in Geneva, is provided by Dance (1966). There is no specimen of *Caryodes* in the Delessert Collection (E. Binder *in litt.* 1977). There is no *Caryodes* specimen present in the Edinburgh Du Fresne Collection (D. Heppell *in litt.* 1977). Enquiries in London and Paris also failed to locate type material.

French Expeditions

McClymont (1885) listed eleven navigators, three of whom were French, who visited Van Diemen's Land. The evidence does not support collection by an English expedition. A close study of the visit of Marion du Fresne to the eastern Tasmanian coast described by Giblin (1928) suggests that his expedition is not likely to have collected the shell. His party made a frustrating search for water over a burnt landscape. Plomley (1984) has pointed out that the party collected only marine shells and du Fresne found the conditions inhospitable. No variations of *Caryodes* conforming to the Leach figure are known from the area of his landing.

There are records of *Caryodes dufresnii* collected by the French from eastern Tasmania. Peron, naturalist with the Baudin expedition (Giblin 1928, Plomley 1984) collected shells which are preserved in the Ferussac Collection in the Natural History Museum in Paris (S. Tiller *in litt.* 1977). Shell form and collection date render this as unlikely to be the source of Leach's shell.

This leaves the expedition of Admiral Bruni D'Entrecasteaux with the naturalist De Labillardiere in 1792 and 1793. The history of the landing at Recherche Bay has been described by Giblin (1928), Pretyman (1954) and Plomley (1984). Comment on the considerable collections does not appear to include snails but it is improbable that *Caryodes* shells were not seen. Labillardiere was a keen observer interested in all living things (Giblin 1928). In addition Labillardiere collected widely in the area from South Cape Bay to Southport Lagoon. Giblin also remarked that earlier navigators had little time for investigation due to other projects.

Shell Form

Caryodes dufresnii is well known for its shell variation. Three subspecies were described by Iredale (1937b) from Launceston, Port Davey and Macquarie Harbour. Of these the first has distinct features. Iredale thought that the type locality could be "north from Hobart" but this does not distinguish the species from other forms nor is there any evidence that the original specimen could have come from such a locality. Iredale's subspecies are based on illustrations by Tenison-Woods (1878).

The shell figured by Leach has a curious flattening of the basal margin partly due to a twist of the columella. No specimens exactly like this have been seen but shells with a twisted columella are known from southern Tasmania. Examples in the Tasmanian Museum collection include E9893 from Lune River and E4341 from Cox Bight both of which have some resemblance to the Leach figure. Specimens from South Cape Bay (E8591) have the basal margin more rounded than in the figure but these also have the twisted columella. The effect of the twist is to broaden the basal margin providing a distinctive appearance. Study of a large number of shells has not revealed equivalent material in another site from which the original material could have been collected.

Iredale (1937b) remarked on the twisted columellar margin present in a Ringarooma shell figured by Tenison-Woods (1878, 6b). In this case the basal margin is deeply curved as a result rather than broadened. However juvenile specimens also have a broadened aperture associated with a twisted columella (e.g. Tenison-Woods 1878, 6a). The belief that such shells are adult variations has caused confusion in the past. Therefore it has been necessary to study many shells before concluding that specimens from South Cape Bay have a satisfactory resemblance to the Leach figure.

Locality Determination

The specimens E8591 in the Tasmanian Museum came from wet forest "near South Cape Bay". National Parks and Wildlife Service staff working in the area have seen specimens (Rounsevell *in litt.* 1986) suggesting a viable population. Labillardiere (1800) described a view in February 1793 towards South Cape from the summit of a mountain. His party spent the night on the edge of the forest near a rivulet. They continued along the shore the next day noting a gentle slope of the back shore and a vein of coal (exposed in a cliff section at South Cape Bay) as they walked. They may have been near South Cape Rivulet but in any case there is no doubt that they traversed the region.

It is therefore possible that this party collected specimens of *Caryodes* in this area. This possibility is supported by a generalised resemblance between shells from the area and the figure of Leach (1815),

together with the peculiar columellar marginal twist.

The region between Recherche Bay and South Cape Bay bounded by 43° 31′S to 43° 37′S and 146° 44′E to 146° 53′E is suggested as the type locality for *Caryodes dufresnii* (Leach 1815).

The Habitat

Vegetation

Caryodes dufresnii as here restricted is a snail of the wet forest. This environment includes rainforest, mixed and wet sclerophyll forests. It is not known to include open country, moorland, sedgeland or grassland communities. A large related form is found in wet forest throughout Tasmania (but not the Bass Strait Islands). Regional variation is apparent but the significance of this and the distribution of varieties has yet to be determined. Prior to European settlement the genus probably occupied every suitable habitat but the distribution is now much reduced (Smith & Kershaw 1981).

Vegetation which may be encountered in the *Caryodes* habitat includes *Nothofagus cunninghamii*, *Acacia melanoxylon*, *Acacia dealbata*, *Atherosperma moschatum*, *Anodopetalum biglandulosum*, *Pomaderris apetala*, *Pittosporum bicolor*, *Blechnum wattsii*, *Dicksonia antarctica* and *Leptospermum* spp. The flora is mainly dominated by *Eucalyptus obliqua* or *E. regnans* and in places dominated by *E. globulus*, *E. viminalis* or *E. delegatensis*.

Twelvetrees (1915b) recorded a range of vegetation in the area of the proposed type locality suggesting that several suitable areas of habitat existed at the time of his visit. His observations are supported by data provided in Waterman & Paterson (1981) and Kirkpatrick & Backhouse (1983). Vegetation maps presented by Jackson (1965), Jarman & Brown (1983) and Kirkpatrick & Dickinson (1984) show that despite considerable modification since Labillardiere's observations extensive areas of forest persist.

Open eucalypt forest extends west from the surface developed on dolerite to that on sedimentary rocks of the Parmeener Supergroup near South Cape Bay, with closed scrub on the higher ground north from South Cape (Waterman & Paterson 1981). The forest opens to sedgeland near the coast in the South East Cape area and an area of mixed forest has apparently survived in the valley of South Cape Rivulet. The *Caryodes* habitat can be expected to be in the eucalypt and mixed forest areas.

Geology and Soils

Accounts of the geology of the South Cape Bay and Recherche Bay region are given by Milligan (1849), Twelvetrees (1915a, 1915b) and Farmer (1979). The main rocks outcropping in the region are Jurassic dolerite, north from South East Cape to Recherche Bay, and Triassic sandstone and shale northeast from South Cape Bay to Recherche Bay. Narrow strips of Quaternary alluvium adjoin Cockle Creek and South Cape Rivulet. The soils (Nicolls & Dimmock 1965) in the area are grey-brown podzolic on dolerite, gradational yellow podzolic soils on the sedimentary rocks and uniform profiles on the Holocene alluvial and dune sands.

Climate

Rainfall maps by the Bureau of Meteorology and Christian & Sharp-Paul (1979) suggest an estimated 1400 mm annual rainfall in the South Cape Bay region. These authors showed that temperatures decrease with distance inland. Modern climatic data are available for Maatsuyker Island and Cape Bruny (Appendix 1). Nunez (1978) graphed rainfall for Maatsuyker Island and his figures provide some indication of rainfall reaching the coast.

Microhabitat

The habitat includes both litter and moss on the ground. The snail seeks shelter under logs particularly where litter has accumulated alongside the log. Litter accumulations against rock outcrops are also favoured. The snail may seek shelter in crevices and cavities of tree trunks in shaded forest and has been observed climbing trees during rain. Some animals may be seen crawling in the open early in the day but seek shelter from sunlight.

ANOGLYPTA LAUNCESTONENSIS (REEVE 1853)

Proposed Type Locality: Mt Maurice Forest Reserve

The species was introduced by Reeve (1853a) as *Helix launcestonensis* and defined by a clear illustration. A description was provided separately (Reeve 1853b). In both cases the locality is given as "Launceston, Van Diemen's Land". However Reeve remarked "collected last summer by Mr Ronald Gunn in a dense beech forest, north-east of Launceston."

Launceston was accepted by Iredale (1937b) but clearly Reeve used the name as the nearest

known locality of which he was aware. His concept of the type locality is clear in the remarks made. The purpose here is to establish this locality. The species is considered at risk (Wells *et al.* 1983) and an area providing adequate security for an existing population should be defined.

Original Material and Locality Determination

Two lots of specimens regarded as syntypes are preserved in the British Museum of Natural History. The original label does not refer to Gunn but Dr P. Mordan (*in litt.* 1986) is confident that these are the type series. The label gives the locality as "V. D. Land". Fortunately Gunn's correspondence (Burns & Skemp 1961) with Sir William Hooker strongly supports the probability that he did collect the material and indicates the locality involved. In a letter dated 17th March 1849, Gunn described a walk "through a forest of *Fagus Cunninghamii* towards the North-East", in October 1848. A letter to Hooker dated 10th May 1849 explains that Gunn had "opened a communication with Mr Lovell Reeve" although no mention is made of the snail shells.

The route taken by Gunn is shown by Burns & Skemp (1961, opp. p.18) as proceeding from Diddleum Plains towards the northeast through myrtle forest. Diddleum was a point of entrance to "the unknown territory" (Hookway *et al.* 1981) and Gunn had a summer sheep run there. Hence there is no doubt as to Gunn's starting point.

The route followed by Gunn passes to the east of Mt Maurice to the valley of the Ringarooma River. This is a similar route to that now followed by the Maurice Road. It is impossible to determine the exact site from which Gunn's shells came. The species is present at a number of sites along and surrounding the route. In order to include as far as possible, the original site together with known existing populations and the Forest Reserve it is necessary to define an area larger than the Reserve.

Therefore the type locality for *Anoglypta launcestonensis* (Reeve 1853) is thought to lie within an area in northeastern Tasmania between Mount Scott and Trenah bounded by 41° 15′S to 41° 21′S and 147° 31′E to 147° 40′E.

The Habitat

Vegetation

Anoglypta launcestonensis is found in scattered localities within rainforest and mixed forest in areas having an annual rainfall approximating 1400 mm or more extending from Mt Arthur easterly to just east of Goulds Country. This region is bounded by 41° 10′S to 41° 25′S and 147° 16′E to 148° 05′E. A copy of a report on field work done in the region is held by the Queen Victoria Museum (Smith & Kershaw, unpub.).

In the type area the following species occur: *Eucalyptus delegatensis*, *Nothofagus cunninghamii*, *Phyllocladus asplenifolius*, *Atherosperma moschatum*, *Tasmannia lanceolata*, *Blechnum* sp. and *Persoonia* sp. Also observed in the habitat are *Eucalyptus regnans*, *E. obliqa*, *Pomaderris apetala*, *Dicksonia antarctica* and *Polystichum proliferum*. Much of the habitat is included in the land systems Diddleum Plains and Mt Maurice (Pinkard 1980). The former according to Pinkard is dominated by *Nothofagus* and sassafras and the latter by eucalypts.

Geology and Soils

The rock cropping out in the type locality is Devonian granodiorite (McClenaghan & Baillie 1975). The soils are yellow gradational podzolic with a clay B horizon (Nicolls & Dimmock 1965). The A horizon is highly organic and shallow with a moss cover or, where eucalypts dominate, a deeper litter cover.

Climate

The annual precipitation is similar to that required for survival of rainforest trees, i.e. 1400 mm (Jackson 1965). The 1400 mm isohyet almost encloses the distribution of *Anoglypta launcestonensis*. Successful populations are found in areas of apparently high rainfall reliability. The nearest rainfall figures available are those of Ringarooma (Appendix 1).

Microhabitat

Anoglypta launcestonensis is a nocturnal animal which is seldom seen in daylight. It prefers the shelter of rotting logs and moss covered surfaces. Destruction by fire of dense shrub and fern understorey has in places revealed high concentrations of shells suggesting that such shelter may facilitate increased population levels. At one site a high mortality of snails was observed following a fire. Habitat differences are most marked between rainforest and mixed forest where the latter has a high *Eucalyptus* litter contribution, but no obvious variation associated with this factor has been observed in these snails. The addition of eucalypt bark and leaves to the rainforest litter appears to favour the presence of *Helicarion* rather than increase the incidence of *Anoglypta* or *Caryodes*.

BOTHRIEMBRYON TASMANICUS (PFEIFFER 1853)

Proposed Type Locality: Maria Island

The species was described by Pfeiffer (1853) who gave the provenance as Van Diémen's Land. In Tasmania *Bothriembryon* is distributed along the eastern and southern coasts and on some islands (Kershaw 1985). It is a snail of the coastal plain from the backshore to a kilometre or so inland.

Pfeiffer's description established the species only. The length quoted of 25 mm fits available material but the diameter does not. Dr A. Solem (pers. comm.) has pointed out that Pfeiffer measured diameter oblique to the shell axis thus obtaining a lower figure than would be now recorded. The white shell colour noted by Pfeiffer suggests an old worn shell as noted by Cox (1868). The words used by Pilsbry (1900) are "opaque white" presumably due to the use of similar material although his alternative colours also suggest gerontic shells. Juveniles from all populations are more or less horny translucent. Both of these authors give "East Coast" as the type locality but Iredale (1937a) follows Pfeiffer.

The taxon *Bothriembryon brachysoma* Pilsbry 1900 also has the type locality "East coast of Tasmania". As there are other populations with a degree of variation it is desirable to clarify this situation.

Original Material

There are two specimens considered to be possible syntypes in the Cuming Collection in the British Museum of Natural History (P. Mordan *in litt.* 1982). There are two labels in Pfeiffer's handwriting, one of which refers to Tasmania and the other to New Caledonia. It is impossible to decide which label should be associated with which shell. The dimensions do not conform to the description in either case and one label refers to a variety. As pointed out by Morden this is not technically part of the type series. Although these shells are part of the Cuming Collection and were identified by Pfeiffer it is not possible to decide when Pfeiffer handled them. While the difference in shell diameter can be ignored the failure of the longitudinal dimensions to fit Pfeiffer's published description must be considered. It seems unlikely that Pfeiffer had these shells in hand when he drew up his description.

The Cuming Collection was described by Dance (1966). Cuming may have obtained the shells from one or more of the many visitors to the eastern Tasmanian coast. Errors in original localities in the Cuming Collection are not unknown. The locality "New Caledonia" on one label strongly suggests that the shell was received from a different source although it is an obvious error. This material does not include the type shell.

The history of Maria Island is well known. Many ships visited Darlington (West 1852) where the species is plentiful.

Shell Form and Locality Determination

Although no specimens as large as those in the British Museum have been seen, both shells have a resemblance to populations found on Maria Island and on the Forestier Peninsula. The difference between shells from these two localities is superficially one of shell colour only. Shells with a pale epidermis occur on Maria Island and this is a very noticeable feature at some sites. Study of shell proportions supports the hypothesis that Maria Island is the source of the Cuming material, including the shell described by Pfeiffer (1853).

Material from Maria Island comparable with Pfeiffer's description is preserved in the Tasmanian Museum. Comparable fresh material has also been studied. The clear resemblance between these shells, the forms recognized by Cox (1868) and Pilsbry (1900) and the original description supports recognition of Maria Island as the source of the original material.

It is believed that Darlington is the original source. The type locality of *Bothriembryon tasmanicus* (Pfeiffer 1853) is determined as that area bounded by 42° 34′S to 42° 40′S and 148° 02′E to 148° 08′E which includes North Maria Island.

The Habitat

Vegetation

Bothriembryon tasmanicus is a snail of the dry sclerophyll forest, woodland and coastal scrub. Some adaptation to wet sclerophyll forest is apparent on the Forestier Peninsula and on Maria Island. A specimen has been photographed on the trunk of *Banksia marginata* on Mt Maria (J. Chick, pers. comm.), the *Banksia* associated with *Callitris rhomboidea*, *Bedfordia salicina*, *Olearia argophylla* and *Richea dracophylla*. This community resembles the disjunct flora on eastern screes described by Brown & Bayley-Stark (1979).

C. Spry, National Parks ranger, collected specimens on the trunks of *Cupressus macrocarpa* adjacent to the coast at Darlington and beneath *Eucalyptus globulus* adjacent to the Bishop & Clerk track. This latter is an area of Pleistocene talus of dolerite with a vegetation of tall eucalypt woodland. A further collection made on Skipping Ridge represents a population within open forest dominated by *Eucalyptus obliqua* with a shrubby understorey. This site appears to be on Permian siltstone (Clarke & Baillie 1984).

The environment is described by Brown & Bayley-Stark (1979). Further climatic data are presented in Appendix 1.

Geology

The geology of Maria Island was described by Clarke & Baillie (1984). At Darlington the shore habitat is one of vegetated dune sands of Holocene age inland from which there is an area of marshy deposits. The bedrock of the type locality includes Jurassic dolerite, Permian and Triassic sedimentary rocks and areas of Quaternary sands. This is typical of the habitat of the species south of Swansea (Forsyth & Gulline 1978, Farmer 1979).

Microhabitat

This snail is found for part of the year on trees, rock surfaces and posts where it is dormant during the day. During the winter it apparently seeks shelter under bark, in litter or under stones. During periods of drought it is very difficult to locate and may be buried in the soil as occurs with related forms in South Australia.

BOTHRIEMBRYON BRACHYSOMA PILSBRY 1900

Proposed Type Locality: Great Oyster Bay coast

Pilsbry (1900) described this snail as a variety of *Bothriembryon tasmanicus* with the type locality "East Coast of Tasmania (Petterd)." The holotype of this taxon is preserved in the Academy of Natural Sciences of Philadelphia. The label and catalogue data are those given in Pilsbry (1900) (A.E. Bogan *in litt.* 1983). Potentially comparable populations have been found on the Freycinet Peninsula (e.g. at Coles Bay), Swansea, Bicheno and Orford. All these populations except those on Freycinet Peninsula are extinct or very nearly so.

Original Material

The type material consists of one shell clearly collected by W.F. Petterd and there are specimens in the Tasmanian Museum from the Petterd Collection. The latter are E938 (labelled "*gunnii* Sow.var *brachysoma* Pils."), E939 (E. Coast Petterd 1889) and E941 (E. Coast). All are comparable and may have been collected in the same locality as *B. brachysoma*. An "Oyster Bay" specimen has dimensions which are almost identical to Pilsbry's shell except for a larger aperture. Legrand (1871) records collections made at Swansea but other records are rare.

Swansea was one of the very early settlements in Tasmania (West 1852, p.547). Freycinet Peninsula was used for grazing purposes requiring frequent contact by sea from Swansea. Hence Petterd could have readily collected throughout the Great Oyster Bay region.

Shell Form

The dimensions provided by Pilsbry (1900) do not fit either the Orford or the Bicheno form but comparable shells from Coles Bay have been studied. A very close resemblance to the type is unusual but the form is recognizable in Coles Bay material. This is of a shell which is shorter and stouter than *B. tasmanicus* (see figures in Kershaw 1985). Specimens from the Swansea area are extremely rare. The only viable populations are on the Freycinet Peninsula north of the Hazards and particularly in the vicinity of Coles Bay.

Locality Determination

The original material probably came from near the shores of Great Oyster Bay either near Swansea or on Freycinet Peninsula. The few Swansea specimens studied are not sufficient to enable a decision but ample material from Coles Bay has been studied. In view of the uncertainty as to the exact site and the probable extent of distribution of the original population, the Great Oyster Bay region is suggested as the type locality of *Bothriembryon brachysoma* Pilsbry 1900.

This region is bounded by 42° 04'S to 42° 10'S and 148° 04'E to 148° 20'E on the eastern coast of Tasmania.

The Habitat

Vegetation

The habits of *Bothriembryon brachysoma* and *B. tasmanicus* are very similar if not identical. The vegetation of the Freycinet Peninsula is predominantly dry sclerophyll forest (Kirkpatrick & Dickinson 1984). At the head of Great Oyster Bay a

narrow belt of coastal vegetation remains but elsewhere most of the country is cleared with a few scattered trees remaining above the shore. By contrast the Freycinet Peninsula is well forested. Descriptions of the vegetation are given in Kirkpatrick & Brown (1980) and Tyson (1981).

M. Johnstone (pers. comm.) has observed snails on the wall and windows of the Ranger's house, on tents and under The Chateau at Coles Bay as well as on shrubs and trees. She lists the following vegetation: *Casuarina stricta*, *Leucopogon parviflorus*, *Acacia sophorae*, *Eucalyptus globulus* and *Banksia marginata*. The snail is common on the sand vegetation of the Richardsons Beach backshore and is very active after heavy rain.

Geology and Soils

The spine of the Freycinet Peninsula is of Devonian granite mountains fringed by some narrow strips of Holocene sands (Forsyth & Gulline 1979). These sands extend across the spit at the northern end of Great Oyster Bay behind Nine Mile Beach toward Swansea where the bedrock is Jurassic dolerite. The soils are mainly yellow duplex podzolic (Nicolls & Dimmock 1965) but there are uniform sand profiles on the dunes. In most cases the A horizon is distinctly sandy or sandy loam often with a litter cover of *Casuarina* or *Acacia* leaves. In some coastal areas the A horizon is very shallow.

Climate

The mean annual rainfall at Swansea is 614 mm (Appendix 1). Freycinet Peninsula's rainfall is within the same range as Maria Island and Orford and is distinctly higher than Swansea. Coles Bay may be more closely comparable in temperature and humidity with Darlington than Swansea (Appendix 1, Brown & Bayley-Stark 1978). Long periods of drought occur during which *Bothriembryon* snails are not in evidence.

Microhabitat

The only apparent difference in the habitat of *Bothriembryon tasmanicus* and *B. brachysoma* is the relationship of the latter to the granite bedrock. Both species are found on the same vegetation and in litter from similar plants. *B. brachysoma* has not been found within wet sclerophyll forest.

CYSTOPELTA PETTERDI TATE 1881

Proposed Type Locality: The Cliff Grounds Reserve and vicinity, Launceston

This species was described by Tate (1881) without a clear type locality designation. No type or any other original material is known. Tate gave the locality "Near Launceston (W.F. Petterd); Southport (B.R. Dyer)". The Southport animal is unknown.

Iredale (1937b) accepted Launceston as the type locality. Hedley (1891) together with Petterd collected *C. petterdi* from the "original type locality, Cataract Hill, near Launceston". This should remove any doubt as to the intended locality for this species. However Cataract Hill is now given over to urban development. There are almost no native molluscs left under the remaining vegetation. *Cystopelta* has not been collected in the area for many years. The species has, however, been found adjacent to a small tributary of the South Esk River about 1.5 km from Hedley's locality.

Locality Determination

The population of *Cystopelta petterdi* extends above the north bank of the tributary from First Basin in the Cataract Gorge to a point almost 1 km west within the Reserve. Near First Basin there are only a few, scattered individuals. These are at considerable risk due to gardening activity and the presence of peacocks in the Cliff Grounds. The original population certainly occupied a large area in the vicinity of the Cataract Gorge, but the present population appears to be confined to the north side of the Gorge. The description of a neotype chosen from the most viable part of the population (grid 508800mE 5411650mN) has been submitted elsewhere (Kershaw 1987).

The suggested type locality is that area bounded by 41° 26′S to 41° 30′S and 147° 02′E to 147° 08′E. This area is inclusive of the original site described by Hedley (1891) and the neotype locality. It also includes the Cliff Grounds Reserve. The area is at high risk from fire and other activities but no other appropriate site has been found.

The Habitat

Vegetation

Cystopelta petterdi is a species of dry sclerophyll forest, woodland and scrub in damp places such as gullies and drainage lines. It is also found in

areas of wet sclerophyll to mixed forest within its Tamar Valley distribution. For example, variations of the animal are found in the Notley Fern Gorge and in wet eucalypt forest at Frankford. Similar variations are present in northeastern Tasmania but the rainforest and mixed forests of this region shelter a different morph.

The vegetation of the West Tamar as described by Brown & Buckney (1983) includes much of the habitat but not the type locality. This area is included in the Tippogoree land system of Pinkard (1980) of open forest dominated by eucalypts. In the neotype locality the species occupies the south-facing slope which is significantly moister than the north-facing slope of the tributary valley (a moisture content relationship in accord with the findings of Nunez, 1983).

The vegetation observed in the neotype locality includes: *Themeda australis*, *Cassinea aculeata*, *Senecio linearifolius*, *Acacia dealbata*, *A. mearnsii*, *Eucalyptus amygdalina*, *E. ovata*, *E. viminalis*, *Notolaea ligustrina*, *Clematis gentianoides*, *Coprosma quadrifida*, *Exocarpos cupressiformis*, *Polystichum proliferum* and *Pteridium esculentum* together with bryophytes. The creek banks adjacent to the type locality population have *Blechnum nudum*, *B. wattsii*, *Dicksonia antarctica*, *Acacia melanoxylon* and *Pomaderris apetala* but these species are absent where the valley widens westerly to open woodland. The vegetation fits the shrubby group within dry sclerophyll forest as defined by Duncan & Brown (1984). *Cystopelta* occurs above the creek bank as occasional individuals. It appears to prefer the slightly better drainage of the slope. The species has not been seen on the dry north-facing slope although there are small areas that appear to be suitable.

The area on Cataract Hill described by Hedley (1891) is believed not to include the north aspect facing the Cataract Gorge. Hedley (1891) collecting with Petterd found the species under logs. While still found in such situations the animals are clearly less common. They also occur in coils of bark and occasionally in litter. They have not been found on tree trunks in this area but elsewhere, in rainforest, animals are present on tree trunks for much or all of the year.

Geology and Soils

The neotype locality has a Jurassic dolerite bedrock (McClenaghan & Baillie 1975) deeply dissected by the Cataract Gorge. There has been downslope movement in some areas resulting in deeper friable loams. A typical profile is a dark brown loam A horizon over a reddish brown clay B horizon. Patches of dark greybrown loam occur.

Climate

The annual rainfall at Trevallyn, the nearest station, is 760 mm. Climatic data for Launceston are given in Appendix 1. Frosts and fogs are common (Bureau of Meteorology 1985). The neotype locality is significantly more sheltered and humid than the adjoining terrain.

Microhabitat

Cystopelta petterdi requires a significantly higher shelter and moisture level than required by introduced slugs. *Cystopelta* does not penetrate the drier woodland within which introduced species can survive. It is also absent from partly cleared timbered areas where there is little effective shelter at ground level and exposure reduces the moisture level. It is never found in gardens or other cultivated environments. *Cystopelta* favours the shelter of clean strips of coiled eucalypt bark. The most successful populations are found where bark is plentiful and moisture level reliable. This is particularly the case where bark rests on prolific blackberry growth. *Cystopelta petterdi* is semi-arboreal and appears distinct at least in this respect from the apparently totally arboreal morph seen in rainforest in northeastern Tasmania.

CYSTOPELTA BICOLOR PETTERD & HEDLEY, 1909

Proposed Type Locality: Near the Magnet Mine, Western Tasmania

This species was described by Petterd & Hedley (1909) who give the habitat as "Magnet Range and Upper Pieman River". At the time Petterd was manager of the Magnet Mine and hence undoubtedly had opportunities to search for molluscs. This factor is also an indication of the part of the Magnet Range in which he may have collected. The country is rugged with large areas densely forested and access is difficult. For these reasons the species has been difficult to find and hitherto has been considered unknown.

Original Material

There are two lots of possible syntype material. Two dried specimens are preserved in the Australian Museum (AM C27807) and one dried specimen is preserved in the Queen Victoria Museum (QVM409 1983/9/4). The identity of these specimens is not recognizable superficially.

The criteria upon which *Cystopelta bicolor* was erected are not visible in dried specimens. In addition a different morph has been found living in the area. Consequently the dried specimens are of little practical value.

Form

It is essential to establish the morphology of the species to enable recognition and establish the validity of the taxon. Specimens collected adjacent to the road to the Magnet Mine in June 1986 have made this possible. These animals compare favourably with the original description including a brown mantle, a green foot and green caudal mucus. This combination of features upon which *Cystopelta bicolor* is based is not present in *C. petterdi*. Individually these features are not enough to distinguish the species and specimens with a green foot are found elsewhere. This taxon has precedence over all others except *C. petterdi*. Therefore the erection of a neotype from the type locality with a description of the anatomy is essential (Kershaw 1987).

Locality Determination

No material has been found in the Upper Pieman River region. The assumption that Petterd collected most of his material near the Magnet Mine together with the results of recent field work (above) favour the Magnet region as the type locality.

The area bounded by 41° 24′S to 41° 30′S and 145° 24′E to 145° 30′E in the vicinity of the Magnet Range and the Magnet Mine near Waratah, western Tasmania, is proposed as the type locality of *Cystopelta bicolor* Petterd & Hedley 1909. This differs from Iredale (1937b) only in the omission of the Upper Pieman area.

The Habitat

Vegetation

The habitat of this species is rainforest. All *Cystopelta* are arboreal to some degree hence this is not a distinguishing feature without further clarification. The colour pattern of the animal coincides remarkably with the stem and foliage colour of shrubs and young trees in the habitat. The green foot of the specimens found was dull rather than bright as described and fades rapidly in preservative. Specimens with a bright green foot have been found in central Tasmania. It is possible that the colour varies with season and environment. Juveniles have a bright translucent green foot colour.

The Magnet Road material was found in scrub regrowth adjacent to the road in a very old log buried in the ground. This has some similarity with the original "scrub" site. The vegetation in and immediately adjacent to the site includes: *Nothofagus cunninghamii*, *Acacia melanoxylon*, *Atherospermum moschatum*, *Bauera rubioides*, *Gahnia grandis*, *Cyathodes parvifolia*, *Eucryphia lucida*, *Leptospermum scoparium*, *Telopea truncata*, *Tasmannia lanceolata*, *Phyllocladus aspeniifolius*, *Cassinia aculeata* and *Juncus* sp. Some of these species are present as mature trees adjoining regrowth.

No specimens were found in the adjacent rainforest either in logs or on trees. They may have been present in the foliage but could not be seen even with torch light. The authors remark on the rarity of their species. Two additional specimens were found to the north of the Hellyer Gorge adjacent to the Murchison Highway. Prolonged search failed to reveal any further specimens but in December 1986 B. Blandford found the species within the Hellyer Gorge.

The Murchison Highway site differed substantially from that of Magnet Road. The vegetation included *Eucalyptus obliqua*, *Acacia melanoxylon*, *Nothofagus cunninghamii*, *Olearia argophylla*, *Pittosporum bicolor*, *Dicksonia antarctica*, *Tasmannia lanceolata*, all of mature growth together with *Pteridium*, fireweed and blackberry along the roadside. The *Cystopelta* were found in coiled bark adjacent to the blackberry.

The rainforest in the type locality is similar to that described by Kirkpatrick (1977) as large crowned rainforest.

Geology and Soils

A large proportion of the type area is classified as the Mt Bischoff Land System on Permian mudstone and slates while the Murchison Highway site is part of the Hampshire Land System on Tertiary basalt (Richley 1978). The Magnet Road site adjoins a quarry in Cambrian rocks (Williams & Turner 1974). The soil has a large proportion of slatey siltstone and mudstone. It is a stoney yellow clay with a shallow humus A horizon with a moss cover in the forest. Adjoining the Murchison Highway a shallow humus clay loam A horizon with a deep brownish yellow B horizon over fragmentary bedrock can be seen in the roadside. Detail on the soils is provided by Richley (1978).

Climate

Nye (1923) observed that rainfall at Magnet was higher than at Waratah. The valley of Magnet Creek is 150 m below Waratah and the neotype locality is a short distance above the Magnet valley floor. He provided tables of monthly rainfall at Waratah. The nearest modern data on rainfall, temperature and humidity (Appendix 1) are from Savage River.

Microhabitat

Cystopelta bicolor has been found in strips of coiled eucalypt bark as well as below logs. Superficially there is a resemblance to the habits of *C. petterdi* but Petterd & Hedley (1909) recorded *C. bicolor* from foliage. The latter species favours much higher humidity.

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(accepted 3 March 1987)

APPENDIX 1

Climatic Data Relevant to Type Localities

Part A: Mean seasonal and annual rainfall (mm)

Mollusca	Locality	Sum.	Aut.	Win.	Spr.	Ann.*
Caryodes	Maatsuyker Is.	240	320	371	313	1244
	Cape Bruny	195	239	276	239	949
Anoglypta	Scottsdale	176	288	361	267	1092
	Ringarooma	198	279	440	314	1231
Bothriembryon	Darlington	167	165	177	160	669
	Orford	157	188	186	185	716
	Swansea	152	156	198	148	614
Cystopelta	Trevallyn	136	190	248	186	760
	Launceston	132	167	237	184	720
	Savage River	300	503	660	494	1957
	Waratah	352	517	732	601	2202
Part B: Mean daily temperature (C)						
Caryodes	Maatsuyker Is.	17	14	11	13	16 Max.
		10	9	7	7	8 Min.
	Cape Bruny	18	16	11	14	15 Max.
		11	9	6	8	8 Min.
Anoglypta	Scottsdale	21	17	12	16	16 Max.
		10	7	3	6	6 Min.
Bothriembryon	Orford	22	19	14	17	18 Max.
		11	8	3	7	7 Min.
	Swansea	21	18	14	17	17 Max.
		11	8	4	7	7 Min.
Cystopelta	Launceston	24	19	13	18	18 Max.
		11	7	3	7	7 Min.
	Savage River	19	15	10	13	14 Max
		9	7	4	5	6 Min.
	Waratah	17	13	8	12	12 Max.
		6	4	1	3	3 Min.
Part C: Average humidity (%)						
Caryodes	Maatsuyker Is.	82	85	86	83	84 a.m.
		77	81	82	79	80 p.m.
	Cape Bruny	76	81	84	78	80 a.m.
		73	75	77	73	74 p.m.
Anoglypta	Scottsdale	71	77	82	74	76 a.m.
		62	65	73	68	67 p.m.
Bothriembryon	Orford	66	77	84	68	74 a.m.
		58	65	68	61	63 p.m.
	Swansea	66	73	77	66	70 a.m.
		59	62	64	60	61 p.m.
Cystopelta	Launceston	61	81	89	71	76 a.m.
		45	59	68	56	58 p.m.
	Savage River	79	87	91	83	86 a.m.
		61	76	83	71	73 p.m.
	Waratah	79	88	93	85	86 a.m.
		67	80	87	77	78 p.m.

* Seasons — Sum. = summer, Aut. = autumn, Win. = winter, Spr. = spring.

Notes: These data are provided by courtesy of the Commonwealth Bureau of Meteorology. The stations selected are the nearest for which data are available. The periods of observation range from 19 years for Scottsdale and Orford to 85 years for Launceston.

VEGETATION HISTORY AND CLIMATE BEFORE THE MAXIMUM OF THE LAST GLACIATION AT CROTTY, WESTERN TASMANIA,

by Eric A. Colhoun and Guus van de Geer

(with two text-figures)

COLHOUN, E.A. & VAN DE GEER, G., 1987 (30:vi): Vegetation history and climate before the maximum of the last glaciation at Crotty, western Tasmania. *Pap. Proc. R. Soc. Tasm.*, 121: 69-74. ISSN 0080-4703.
Department of Geography, University of Newcastle, N.S.W. 2308 (E.A.C.); and Department of Geography, University of Tasmania, G.P.O. Box 252C, Hobart, Tasmania 7001.

Organic-rich sands and silts estimated to be about 25 000 to 40 000 years in age indicate that alpine-subalpine herb, shrub and heath vegetation communities occurred at 250 m altitude in the King Valley prior to the maximum phase of the Last Glaciation. Mean temperature was probably 5°C colder than at present and the climate was wet.
Key Words: Vegetation history, climate, Pleistocene, Tasmania.

INTRODUCTION

During construction of Crotty Road in the King Valley of western Tasmania the Hydro-Electric Commission exposed a small section of organic-rich deposits on the eastern side of the road 3 km south of the junction with the Lyell Highway (fig. 1). The deposits occur at an altitude of 250 m a.s.l. in a small hollow and consist of bedded organic silts, sands and small gravels of 10-30 mm diameter. They underlie sandy fibrous peat and fragmented quartzite deposits, and rest on outwash gravels and till that belonged to the Comstock Glaciation, the Penultimate glaciation of the King Valley (Kiernan 1983). By analogy with many other exposures in the region, the sandy fibrous peat is interpreted as being of Holocene age. The fragmented quartzite deposits lie south of the limits of the Last or Margaret Glaciation and are interpreted as having been formed by frost shattering of surface gravels from the Comstock age glacial deposits that moved downslope over the organic-rich deposits during the maximum stage of the Last Glaciation (about 25 000-10 000 yr b.p.). It, therefore, seemed that the underlying organic-rich deposits would reveal, through pollen analysis, the nature of the vegetation that occurred in the middle King Valley prior to the ice attaining its maximum extent in the West Coast Ranges during the Last Glaciation.

This paper records the environment and stratigraphy of the site, and describes the results of the pollen analysis. The deposits were sampled at 0.05 m intervals, and the samples were prepared by the method of Faegri & Iversen (1975). A sum of 300 grains of dry-land taxa was used where possible, and sedges were omitted from the sum. The taxonomic nomenclature follows Curtis (1963, 1967), Curtis & Morris (1975), Willis (1970), and Wakefield (1975).

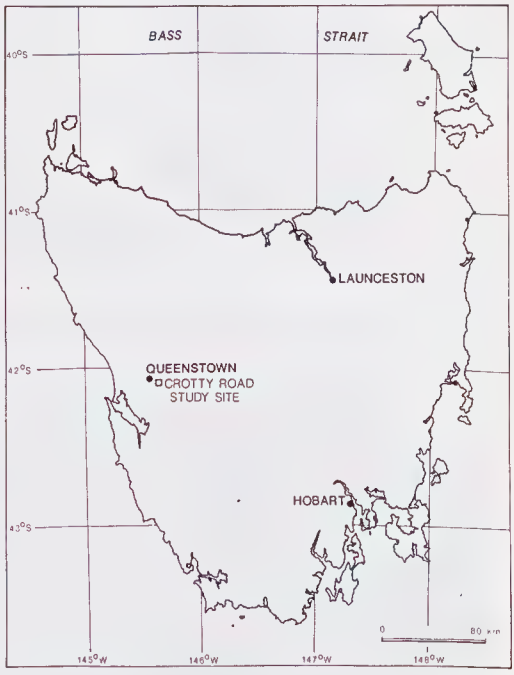

FIG.1 — Location of Crotty Road site, western Tasmania.

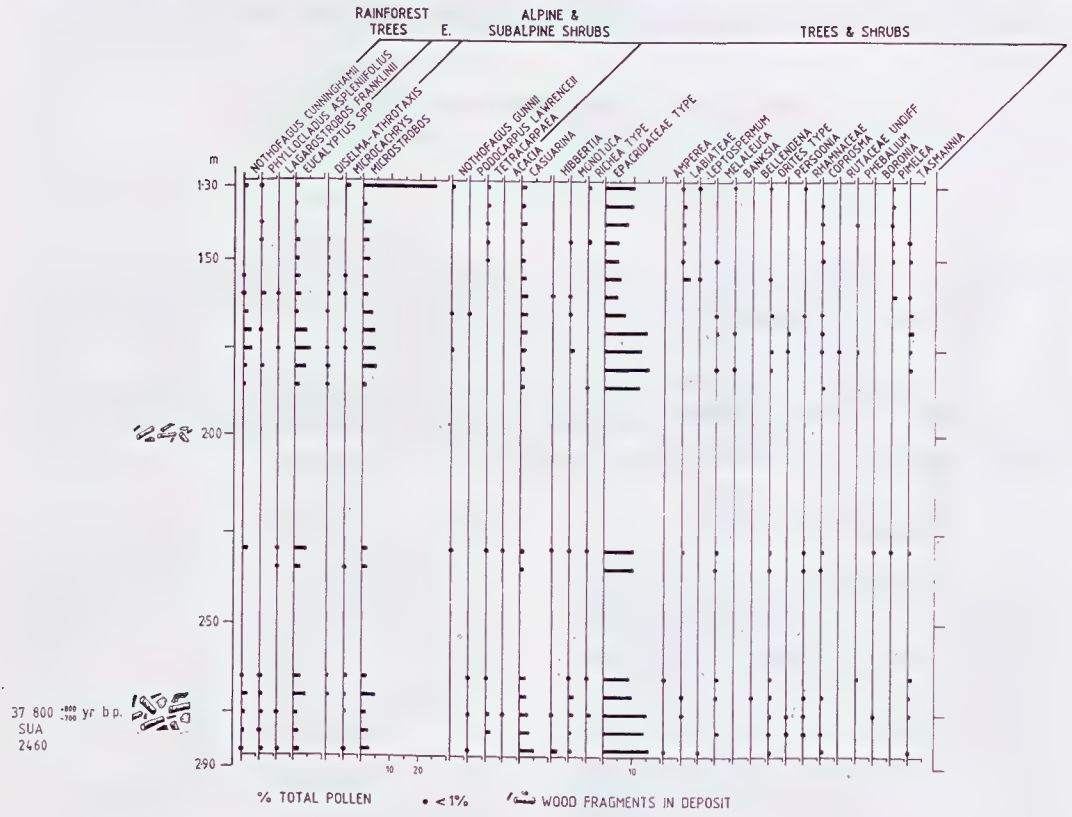

FIG.2 — Relative pollen diagram of Crotty Road organic-rich deposits.

PRESENT ENVIRONMENT AND VEGETATION

The site occurs at an altitude of 250 m on the western side of the King Valley in the lee of Mount Owen in the south-central part of the West Coast Ranges. Ordovician Owen Conglomerate and Cambrian volcanic rocks are exposed on the mountain slopes to the west and in the beds of the streams that cut through the glacial deposits. There is no reliable climatic data for the King Valley which being leeward of the mountains would be slightly drier than Queenstown with 2 520 mm precipitation per annum. Winter mean temperatures of 7.1° C for July and summer mean temperatures of 14.8° C for January would be similar. Frosts and fogs associated with strong temperature inversions are common in winter. The gently undulating to sloping glacial moraine and outwash terrace deposits are very poorly drained and are covered with Holocene peat of 0.3 to >1.5 m in thickness. Although potentially in a region of temperate *Nothofagus cunninghamii* rainforest vegetation, much of the valley floor is covered with epacridaceous heathland and *Gymnoschoenus sphaerocephalus* (buttongrass) sedgeland, with wet scrub of *Leptospermum scoparium*, and *Melaleuca squamea* and *M. squarrosa*, and *Eucalyptus simondsii* forest on the better drained slopes of the hills. To what extent the heath, sedge and scrublands are products of soil water-logging and to what extent they are products of aboriginal and European firing is debatable, but firing during the late 19th and 20th centuries has certainly played an important part in their maintenance as non-forested areas (Kirkpatrick 1977, Kirkpatrick & Dickinson 1984).

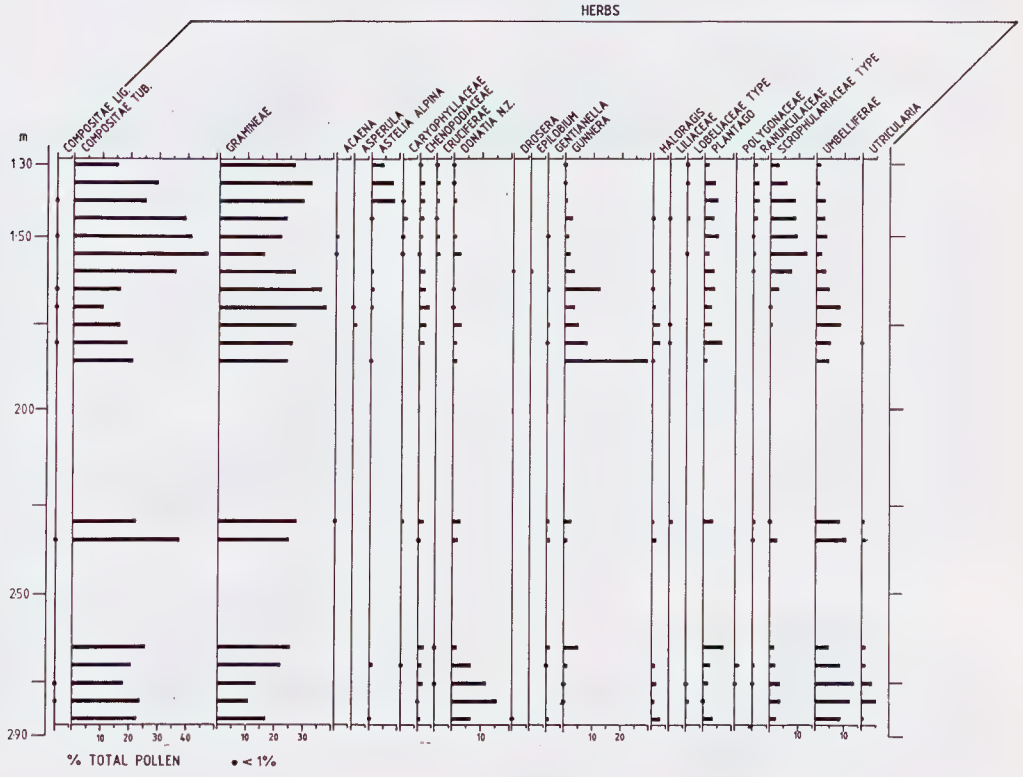

FIG. 2 — (Continued)

STRATIGRAPHY AND DATING

The stratigraphy of the small lake basin consisted of:

Depth

0 — 0.50 m sandy peat

0.50 — 1.50 m quartzite and Owen Conglomerate gravels, 10-100 mm in diameter, angular to sub-rounded in shape in an organic stained sandy matrix. Deposit poorly sorted.

1.30 — 2.90 m bedded organic silts and sands, with abundant vertical rootlets of Restionaceae and drifted wood fragments at 2.00 m and at 2.70-2.80 m depth. Rootlets and wood fragments are carbonised but no charcoal fragments were observed.

2.90 — 3.50 m glacial gravels of quartzite and conglomerate of 10-150 mm size. The gravels are poorly-sorted and bedded, but are moderately rounded.

3.50 — >4.00 m till of Comstock glacial age which consists of quartzite, conglomerate and volcanic clasts, with frequent erratics of Jurassic dolerite and rare cobbles of Permian mudstone.

The entire thickness of lake sediments has been penetrated by humic acids derived from the surface peat deposits and heath vegetation.

Although not an ideal site for radiocarbon dating, one sample of well preserved wood (probably *Leptospermum* or *Melaleuca*) from 2.70-2.80 m depth gave a result of 37 800 +800/–700 yr

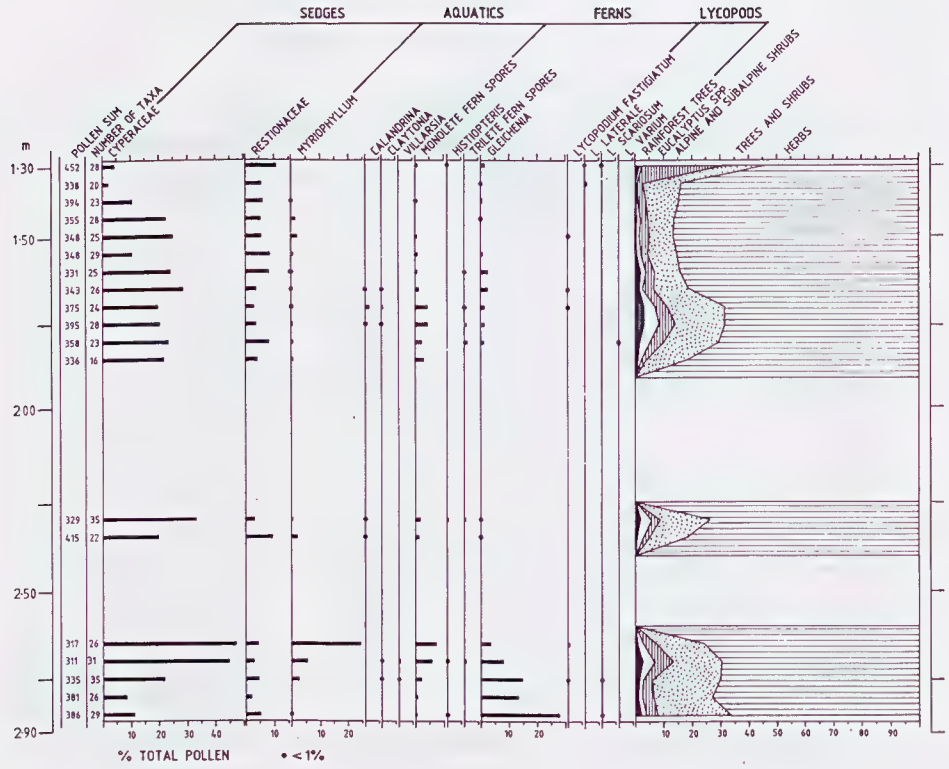

FIG. 2 — (Continued)

b.p. (SUA 2469). The sample was pretreated with a 2:1 benzene:ethanol, then ethanol, then water, and cellulose was isolated with sodium chlorate. The result seemed to confirm that the base of the organic-rich lake deposit has a maximum age of about 40 000 years. The interpretation of the stratigraphy presented suggests an approximate age of 25 000 years for the top.

THE POLLEN DIAGRAM

The relative pollen diagram (fig. 2) shows that the vegetation consisted mainly (70-80%) of herbaceous taxa. Woody taxa generally represent less than 20-30% of the pollen. Alpine and subalpine taxa are generally about 5%, and *Eucalyptus* spp. and rainforest taxa rarely attain 5%. There is such uniformity in the whole profile that it cannot easily be divided into meaningful biostratigraphic zones, the pollen assemblages indicating that the sequence probably occurs within one zone. The nature of the vegetation communities that occurred in the area when the deposits accumulated is suggested by the constituent taxa.

Examination of a concentration pollen diagram not published here showed that concentrations fluctuated greatly from 10 x 10^3 to 350 x 10^3 grains/gm, the low concentrations being associated mainly with sandy sediments and the high concentrations with organic-rich sediments. The concentration values do not have markedly different peaks from the percentage values and merely confirm the relative degrees of importance of the plant groups to be described.

The very low quantities of the temperate rainforest taxa *Nothofagus cunninghamii*, *Phyllocladus asplenifolius* and *Lagarostrobos franklinii* indicate that there was no extensive occurrence of lowland rainforest in the region. The low percentages are consistent with their having been

produced by isolated pockets of rainforest trees/shrubs in protected sites or by small stands close to treeline on the mountains. This rainforest component can be regarded as no more than background values for the pollen rain that could have been transported from other areas to the site. However, all Last Glacial age pollen diagrams from western Tasmania studied so far have shown a small component of rainforest pollen which seems to support the suggestion that small pockets or individual rainforest trees/shrubs were widespread (Colhoun 1985a, Colhoun & van de Geer 1986, van de Geer *et al.* unpublished).

The very high herbaceous component dominated jointly by Gramineae and Compositae Tubuliflorae is also typical of diagrams from western Tasmania for the period preceding the maximum of the Last Glaciation (about 25 000 to 40 000 yr b.p.). The Gramineae and Compositae, together with other associated herbs and shrubs, indicate that the area was probably vegetated by a mosaic of alpine and subalpine herbaceous, shrub and heath communities such as would occur close to climatic treeline today.

The 5-10% of *Astelia alpina* in the upper part of the diagram indicates wet alpine to subalpine conditions while the 10-15% of *Donatia novae-zelandiae* near the base of the diagram suggests alpine conditions. In addition, substantial quantities of pollen of Chenopodiaceae, *Plantago*, Ranunculaceae, Scrophulariaceae and Umbelliferae are common in diagrams from alpine and subalpine environments, while *Gunnera* and *Gleichenia* may also occur. Although the associated herbs point to the existence of a wet alpine-subalpine environment, it is known that these taxa can occur occasionally in the lowlands of southwestern Tasmania today providing there is no competition from scrub or forest vegetation (Kirkpatrick & Duncan 1987). However, the pollen values are too high to be attributed to the isolated occurrences of plants or groups of plants and suggest that their occurrence was widespread.

The relatively large values for *Microstrobos niphophilus*, together with frequent *Diselma-Athrotaxis* and *Microcachrys tetragona*, and occasional *Nothofagus gunnii* and *Podocarpus lawrenceii* pollen, are also indicative of wet alpine-subalpine shrub communities. The high Epacridaceae T-type values could be either a product of subalpine vegetation or of wet heathland communities in association with Cyperaceae and Restionaceae. Although small quantities of *Eucalyptus*, *Acacia* and *Casuarina* pollen occur, which indicate the presence of sporadic trees, the values are too low to suggest the presence of woodland. The absence of the treeferns *Dicksonia antarctica* and *Cyathea* spp., of *Atherosperma moschatum* and *Eucryphia-Anodopetalum* type, and of *Pomaderris apetala*, *Anopterus glandulosus*, and *Cenarrhenes nitida* from the record clearly indicates that neither wet mixed forest nor wet sclerophyll forest occupied the floor of the King Valley during this period.

The data, therefore, seem to substantiate the initial suggestion that the valley floor was occupied by a number of alpine-subalpine herb, shrub and heath communities with occasional sclerophyll trees and rainforest trees/shrubs thinly scattered over the landscape. The associations point to a moist, cool environment that would be representative of near-treeline conditions today which occur at 1100 m altitude. If so, the treeline would have been lowered at least 850 m which implies an average temperature reduction of at least 5° C. This value is 1.5° C less than that inferred from snowline data for the maximum phase of the Last Glaciation on the West Coast Range (Colhoun 1985b).

COMPARISONS

Interpreted as representing the period between about 25 000 and 40 000 yr b.p., the pollen assemblages are very similar to those represented in the Henty Bridge diagram which is dated from about 20 000 to >35 000 yr b.p. and to Zone 3 of the Tullabardine Dam diagram which is dated from about 25 000 to 50 000 yr b.p. (Colhoun 1985a, Colhoun & van de Geer 1986). They are also not very different from those of Zone 3 in a diagram from Newall Creek to the west of the West Coast Ranges which probably dates from about 25 000 to >40 000 yr b.p. (van de Geer *et al.* unpublished). The Crotty diagram, though showing that there was some spatial variability in the lowland plant communities represented in western Tasmania during the period that preceded the maximum phase of the Last Glacial Stage, indicates that the climate was cold and that most of the vegetation consisted of wet subalpine to alpine communities.

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THE HOLOCENE EVOLUTION OF RHEBAN SPIT, TASMANIA 2. SOIL DEVELOPMENT TRENDS

by G.M. Bowman

(with two tables and nine text-figures)

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Calcareous sands and podzols of four different ages (0, 3 100, 4 200 and 5 500 calendar years) form a soil chronosequence at Rheban Spit, a prograded sand barrier, near Orford on the east coast of Tasmania. In terms of profile morphology the soils range from undifferentiated quartz sand with shell at the youngest site, to a well-developed podzol with prominent A_1, A_2 and B horizons at the oldest site. Age trends are derived for a number of soil features, the most significant of which are the leaching from the sediments of detrital marine shell carbonate, the increase in organic matter content in the A and B horizons, the decrease in profile pH, the progressive development of A_2 and B horizons in terms of acid-extractable iron and aluminium, the increase in thickness of the B horizon and the decrease in the average concentration of cations in the profiles. Most of these age trends are in accord with those derived from soil chronosequences in New South Wales and overseas, but some are markedly different.

Key Words: Rheban Spit, Tasmania, soil chronosequence, podzols, soil age trends, soil classification, Factual Key.

INTRODUCTION

Podzol soil profiles are extensively developed in quartzose sandy deposits along the eastern coast of Australia. Early studies at Woy Woy, New South Wales (Burges & Drover 1953), first identified the potential of these coastal podzols for soil chronosequence investigations (studies of the rate and mode of soil development). However, more systematic investigations of this type have been carried out only relatively recently: Bowman (1979, 1987) concentrated on Holocene sand barrier podzols in New South Wales, while Thompson (1981, 1983) and co-workers studied Holocene and Pleistocene podzols in the dune sands of south-eastern Queensland.

The progressive increase in age across a Holocene beach-ridge plain provides an ideal spatio-temporal framework for soil chronosequence studies (Bowman 1986a). In such situations, the "time factor" in pedogenesis (Jenny 1941) can be quantified by radiocarbon dating comminuted marine shell deposited with the sediments. The uniformity of the quartzose sands which form the coastal barriers of eastern Australia minimizes complications due to differences in the "parent material" pedogenic factor (Jenny 1946, Bowman 1979). Similarly, the simple ridge/swale morphology of most prograded sand barriers (Thom *et al.* 1978) allows the "relief factor" to be effectively negated by confining the study to one topographic position, i.e. either ridge crest or mid-swale (Thompson & Bowman 1984). Vegetation zonation and succession on these barriers have been documented (e.g. McDonald 1971, 1973, Osborn & Robertson 1939, Pidgeon 1940), allowing the "plant factor" to be assessed without many of the conceptual and practical problems envisaged by soil chronosequence theoreticians (Crocker 1952, Jenny 1958, Olson 1958). In addition, the mild coastal climate of eastern Australia is relatively uniform and unlikely to have changed significantly during the last 7 000 years.

This paper expands the literature on eastern Australian podzols by documenting the characteristics and pedogenic development of a soil chronosequence in eastern Tasmania, an area in which such an investigation had not been undertaken previously.

ENVIRONMENTAL SETTING

The study was carried out on Rheban Spit, a small prograded sand barrier on the eastern coast of Tasmania, in the lee of Maria Island. A complementary paper (Bowman 1986) describes the physical setting, Holocene age structure, geomorphic evolution and sediment characteristics of Rheban Spit, thereby providing the first dated soil chronosequence in Tasmania and pedogenic background data for the present study.

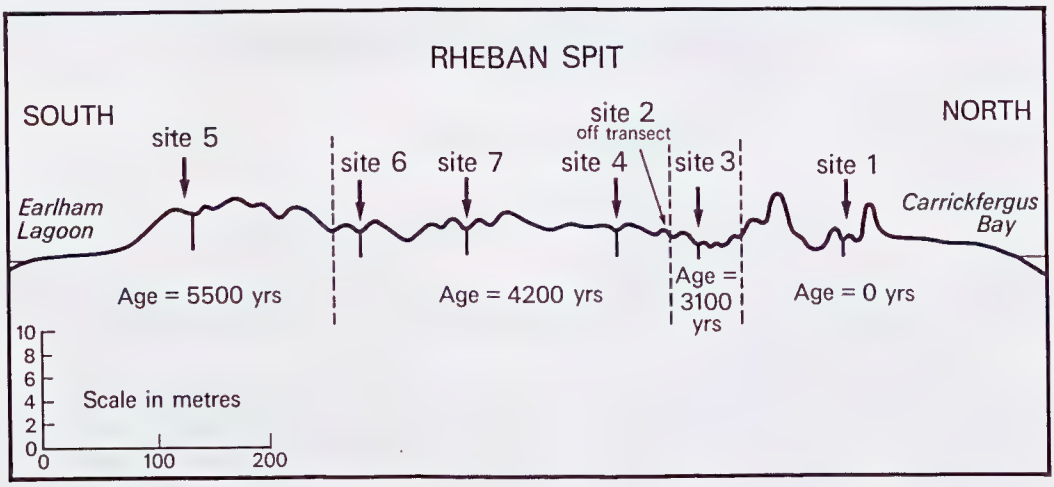

FIG.1 — Cross-section of Rheban Spit showing soil sampling sites 1 to 7 and rounded calendar ages assigned to each (after Bowman 1986).

Monthly rainfall and rainday figures (table 1) are based on observations at Rheban Farm but the temperature and humidity values relate to Orford, which is located about 10 km north of Rheban Spit. These data show that the area experiences mild summers and cool to cold winters, with a moderate rainfall that is very evenly distributed throughout the year.

The vegetation of Rheban Spit has been described in some detail (Bowden & Kirkpatrick 1974) as an open forest of *Eucalyptus globulus*, *E. viminalis* and *Acacia dealbata* on the uncleared beach-ridge plain, whereas the frontal dunes (where vegetated) carry associations dominated by *Banksia marginata*, *Ammophila arenaria*, *Pteridium esculentum* and various low herbs.

Rheban Spit is composed of well-sorted, fine-to medium-grained, quartzose sand of marine origin. Apart from the sand of the youngest foredunes, which has slightly different characteristics from that of the other depositional units at Rheban, the sediments provide a uniform parent material for soil development. There is only slight variation in mineralogy and granulometry both within and between depositional units (Bowman 1986, tables 3 and 4).

TABLE 1

Climatic data for Rheban Farm and Orford, Tasmania. Source: Bureau of Meteorology (1975).

	J	F	M	A	M	J	J	A	S	O	N	D	Yr
Rheban Farm													
Av. rainfall, mm	48	58	47	47	62	64	52	53	41	55	56	67	650
Median rainfall, mm	42	42	41	37	47	46	46	40	37	49	39	59	590
Av. raindays	9	8	9	9	10	11	11	12	11	11	11	10	122
Orford													
Av. daily max. temp., °C	22.1	22.5	21.3	19.6	15.9	13.6	13.8	14.1	15.8	17.8	18.3	20.1	17.9
Av. daily min. temp., °C	11.2	12.3	10.0	8.3	5.6	3.0	2.5	3.5	4.4	6.1	8.4	9.4	7.1
Av. daily rel. humidity, %	61	64	56	64	74	79	78	74	61	59	63	59	66

METHODS

Field Sampling

The seven sites used previously for stratigraphic and sedimentologic analyses (Bowman 1986) were used in the present soil investigation. Six of these were located on the transect line established across the eastern end of the spit by Bowden & Kirkpatrick (1974) and an additional site was located so as to sample adequately one of the progradational units. The rounded calendar age (in years b.p.) assigned to each sampling site in Part 1 of this paper is here assumed to represent soil age, i.e. the elapsed time since the initiation of soil development at that site (Bowman 1987). Hence, the ages assigned to the soil profiles at Sites 1 to 7 are 0, 4 200, 3 100, 4 200, 5 500, 4 200 and 4 200 years, respectively (fig. 1). The identical age of 4 200 years for Sites 2, 4, 6 and 7 reduces the number of time-dependent soil profiles in the Rheban chronosequence but still allows the use of profiles of four different ages.

At each site pits were used for description and sampling (at 0.04, 0.15 and 0.3 m of the upper part of the soil profile) and auger samples were taken at 0.3 m intervals from the pit floor to the water table. Selected samples were also taken to represent adequately the A_1, A_2 and B horizons. The pedological features of each soil profile were recorded inluding the thickness, lower boundary configuration, structure and dominant colour (Munsell notation) of each horizon.

Laboratory Analyses

In the laboratory, pH was measured in a 1:5 water suspension and 10% hydrochloric acid was used to test for the presence of marine shell carbonate (deposited with the quartzose marine sediments). Total organic matter content of the <4 mm fraction was measured by weight loss following low temperature ignition of 2 g subsamples, previously oven-dried at 105° C for 24 hours (*inter alios* Mitchell 1932). This technique is sufficiently accurate, given the absence of clay minerals in these arenaceous sediments and the furnace temperature being raised to 450° C, but no higher (Ball 1964). The ashed samples were then digested in hydrochloric acid for 18 hours at 90-95° C, using cold finger condensors to minimise evaporation. The resulting digests were filtered, made up to constant volume and the concentrations of six elements were determined by atomic absorption spectroscopy.

RESULTS

Soil Profile Morphology

The morphology of the Rheban soils ranges from undifferentiated sand at Site 1, to moderately well-developed podzol profiles towards the landward side of the Spit (Bowman 1986, fig. 2). Selected morphological features of the Rheban profiles are given in table 2, together with information on shell carbonate occurrence and sample pH. The following general trends may be observed in the data.

A_0, A_1, A_2, B and C horizons are present in all the Rheban profiles, except at Site 1, where no horizon differentiation could be detected. With the exception of this site, the thickness of the A_0 and A_1 horizons is consistent across all the sites, but the A_2 and B horizons are of variable thickness, both in absolute terms and in the proportion of total profile depth. Except for the lower boundary of the A_1 horizon at Site 3 (classified as "sharp even": Northcote 1979), all other horizon boundaries are "gradational even".

Dominant horizon colours are mostly 10YR hue, but include some 2.5Y (Munsell Soil Color Charts 1975). Value/chroma ratings for the A_1 horizons all fall in the VC2 group (Northcote 1979), whereas the A_2 horizon ratings are in groups 2 and 3. Although B horizon dominant colours are well clustered, they overlap three value/chroma groups (VC2, 3 and 4).

The field-determined texture of all soil horizons was "sand" and all had "sandy" fabric (Northcote 1979). Parts of the B horizon at Sites 2, 4, 5, 6 and 7 had an "apedal massive" and weakly coherent structure but the remainder of these profiles and the entire soil profile at Sites 1 and 3 had "apedal single grain" structure (Northcote 1979).

Shell Carbonate

Reaction to the HCl test for the presence of marine shell carbonate ranged from moderate to strong down the Site 1 profile. However, no samples from above the watertable at the other sites gave a positive reaction.

Soil Reaction

Sample pH differentiates Sites 1 and 3 from the other soil sites at Rheban. All pH values for Site 1 were greater than 8.0 (mean = 8.4), with the exception of the surface sample (pH = 7.3). Site 3

TABLE 2

Soil profile morphology data for Rheban sampling sites.

	HORIZON	DEPTH OF LOWER HORIZON BOUNDARY mm	SAMPLE DEPTH mm	NATURE OF LOWER HORIZON BOUNDARY	DOMINANT HORIZON COLOUR	HORIZON STRUCTURE	SHELL CARBONATE TEST	HORIZON pH	OTHER FEATURES
SITE 1 AGE = 0 yrs PPF = Uc1.11	Nil	–	40 150 300 610 910 1220 1520	–	2.5Y 7/2	ASG	Moderate reaction Grading to strong reaction	8.46	No surface litter Few Spinnifex roots No visible organic matter Some shell visible, increasing with depth Watertable not reached
SITE 3 AGE = 3100 yrs PPF = Uc2.21	A_o	0	–	–	–	–	–	–	Decomposing litter
	A_1	60	40	S-E	10YR 6/1	ASG	Nil	6.60	Thin mat of fine roots and organic material
	A_2	150	150	G-E	10YR 7/2	ASG	Nil	6.25	Few fine roots Little o.m.
	B	450	300	G-E	2.5Y 6/4	ASG	Nil	6.40	Very few roots Little o.m.
	C	1210	610 910 1220	–	2.5Y 7/3 10YR 7/2	–	Nil	6.85	No organic matter
	W.T.						Strong		Brown groundwater
SITE 2 AGE = 4200 yrs PPF = Uc2.22	A_o	0	–	–	–	–	–	–	Decomposing litter
	A_1	100	40	G-E	10YR 4/1	ASG	Nil	6.20	Abundant organic matter Fine matted roots
	A_2	460	150 300	G-E	10YR 7/2	ASG	Nil	5.15	Few fine roots Less o.m. than above
	B	1370	610 910 1220	G-E	10YR 6/4 with mottles of 10YR 6/6	ASG AM (100-130) ASG	Nil	6.25	Little visible o.m. Friable consistency Few small nodules
	C	1830	1520 1830	–	10YR 7/3	–	Nil	6.55	No o.m. or roots
	W.T.						Nil		Brown groundwater
SITE 4 AGE = 4200 yrs PPF = Uc2.22	A_o	0	–	–	–	–	–	–	Decomposing litter
	A_1	100	40	G-E	10YR 6/2	ASG	Nil	6.10	Rich in organic matter Matted fine roots
	A_2	350	150 300	G-E	10YR 7/2	ASG	Nil	5.25	Few roots Little organic matter evident
	B	1370	610 910 1220	G-E	10YR 6/4 with mottles 10YR 6/5	ASG AM (76-121) ASG	Nil	5.62	Friable consistency No roots observed Little organic matter
	C	2130	1520 1830 2130	–	10YR 7/3	–	Nil	5.80	
	W.T.						Nil		Brown groundwater

TABLE 2 (cont.)

	HORIZON	DEPTH OF LOWER HORIZON BOUNDARY mm	SAMPLE DEPTH mm	NATURE OF LOWER HORIZON BOUNDARY	DOMINANT HORIZON COLOUR	HORIZON STRUCTURE	SHELL CARBONATE TEST	HORIZON pH	OTHER FEATURES
SITE 6 AGE = 4200 yrs PPF = Uc2.22	A_o	0	–	–	–	–	–	–	Decomposing litter Some charcoal
	A_1	60	40	G-E	2.5Y 5/1	ASG	Nil	6.90	Organic matter rich Fine matted roots
	A_2	280	150	G-E	7.5YR 7/1	ASG	Nil	5.02	Few roots Little o.m.
	B	1520	300 610 910 1220 1520	G-E	10YR 6/4 with mottles of 10YR 6/5	ASG AM (46- 137) ASG	Nil	5.59	Friable consistency Single large root at 152 cm Very little o.m.
	C	2130	1830 2130	–	10YR 7/4	–	Nil	5.85	No o.m. No roots
	W.T.						Nil		Grey-brown Groundwater
SITE 7 AGE = 4200 yrs PPF = Uc2.22	A_o	0	–	–	–	–	–	–	Decomposing litter
	A_1	60	40	G-E	2.5Y 5/1	ASG	Nil	6.12	Matted roots O.M. rich
	A_2	280	110 150	G-E	10YR 7/1	ASG	Nil	5.04	Few roots Little o.m.
	B	1370	300 610 910 1220	G-E	10YR 6/4 with 10YR 6/6 mottles	ASG AM (61- 120) ASG	Nil	5.50	No o.m. No roots Friable consistency
	C	2280	1520 1830 2130	–	10YR 7/3	–	Nil	5.88	No o.m. No roots
	W.T.		2440				Nil		Brown groundwater
SITE 5 AGE = 5500 yrs PPF = Uc2.23	A_o	0	–	–	–	–	–	–	Decomposing litter
	A_1	100	40	G-E	10YR 6/2	ASG	Nil	6.30	Rich in organic matter Matted roots
	A_2	250	150	G-E	10YR 7/2	ASG	Nil	5.70	Few roots Some organic matter
	B	1680	300 610 910 1220 1520	G	10YR 7/4 with 10YR 5/6 mottles	ASG AM (60- 100) ASG	Nil	5.95	Friable consistency Few roots Little visible o.m.
	C	3350	1830 2130 2440 2740 3050 3350	–	10YR 8/4	–	Nil	6.14	No visible o.m. Few roots
	W.T.						Nil		Brown groundwater

PPF = Principal Profile Form; ASG = apedal single grain; AM = apedal massive G-E = gradational-even; S-E = sharp-even; W.T. = water table.

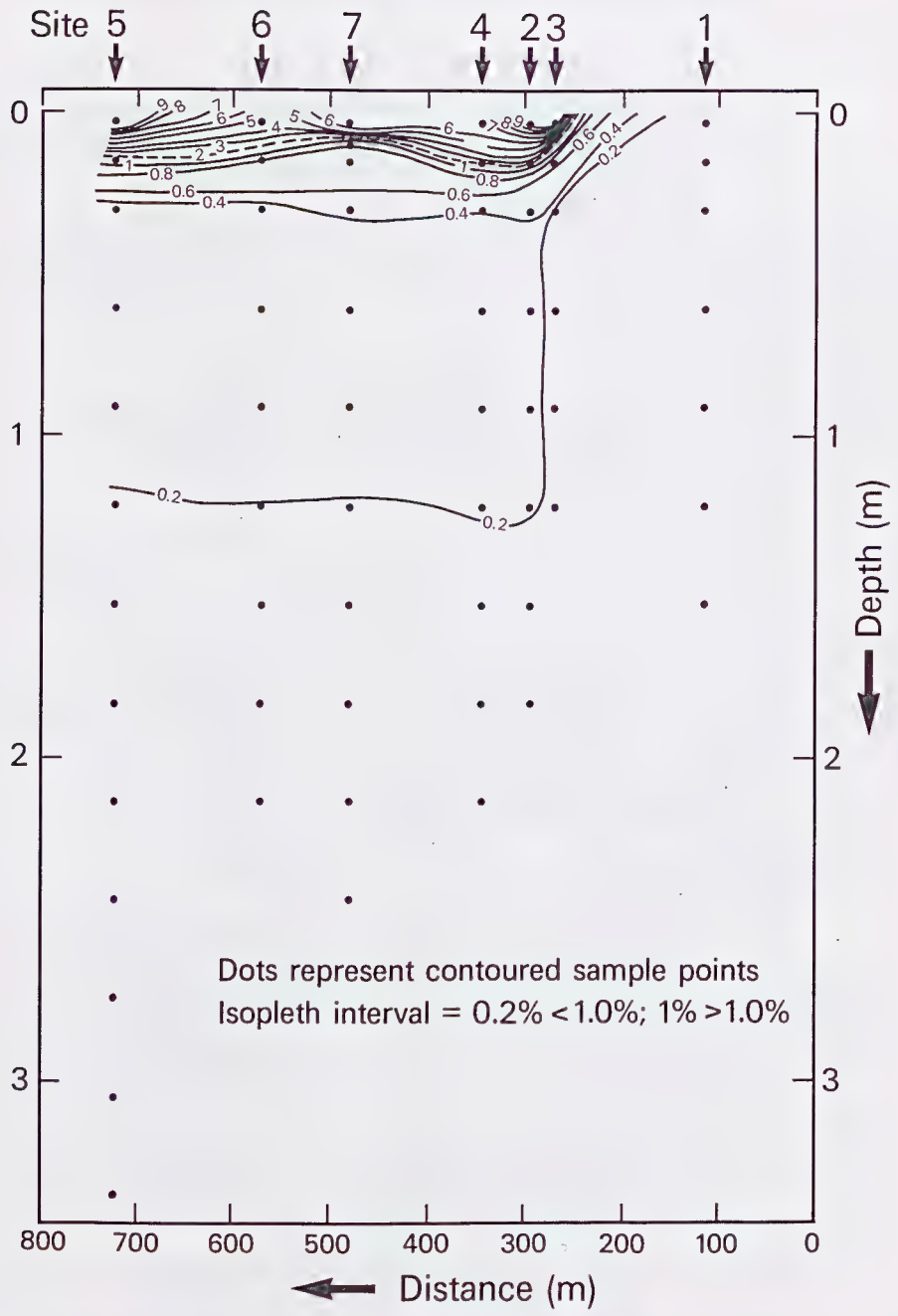

FIG.2 — Contoured cross-section (isogram) showing distribution of organic matter (as % O.M.) in Rheban Spit soils. Horizontal scale indicates distance from Carrickfergus Bay along section; vertical scale indicates sample depth. Note dual isopleth interval.

values all exceeded pH 6.0 (mean = 6.9), whereas subsurface samples from the remaining sites mostly had pH values below 6.0 (table 2). The mean pH for all samples from Sites 2, 4, 5, 6 and 7 were 6.1, 5.6, 6.0, 5.7 and 5.6, respectively.

Organic Matter

Distribution of organic matter in the Rheban soils is depicted in figure 2 by means of an isopleth cross-section (termed an isogram after Ryan & McGarity 1978). The horizontal axis of the isogram represents distance along the Rheban transect from the Carrickfergus Bay shoreline; the vertical axis shows the depth of sampling points. Dots indicate the organic matter determinations used to construct the isopleths (data from Bowman 1979). A dual isopleth interval was used, with 0.2% increments up to an organic matter content of 1.0%, and 1.0% increments above this figure. This arrangement allows both the sharp near-surface changes in organic matter content and the more subtle subsurface transitions to be adequately represented. The main feature of the distribution pattern shown in figure 2 is the very low organic matter content in the subsurface at all sites (<0.2% o.m.).

Distribution of Extractable Elements

Results of the analyses of hydrochloric acid-extractable cations are presented as isograms in figure 3 (after Bowman 1979). Note that some of these isograms use a geometric isopleth ratio while others use an arithmetic isopleth interval to best portray the element distribution patterns. However, all isograms have the same horizontal and vertical scales. In deriving element age trends for the Rheban chronosequence (see below), the element distribution patterns were used to select concentrations representative of the A_1, A_2, B and C horizons at each soil site. The main features of the element distribution patterns shown in figure 3 are:

Iron

All profiles landward of Site 3 exhibit moderate development of both A_2 and B horizons (in terms of iron distribution), although the A_2 horizon at Site 7 appears anomalously thin (fig. 3A). A pronounced discontinuity exists in the upper profile between Sites 1 and 3, with another between Sites 2 and 3. These probably reflect the age differences between the successive progradational units at Rheban. Below a depth of 1 m however, iron distribution forms a relatively systematic pattern across Rheban Spit. The exception is a small irregularity near the base of Site 2, possibly caused by a minor concentration of heavy minerals (but not evident in sand grain counts: Bowman 1986, table 4).

Manganese

Relatively high concentrations of acid-extractable Mn are evident in the upper soil profiles except at Site 1 (fig. 3B). Vertical discontinuities occur on either side of Sites 3 and 7 but the distribution of manganese in the subsurface is relatively uniform.

Aluminium

As with the iron distribution pattern, pronounced vertical discontinuities are apparent between Sites 1 and 3 and between Sites 2 and 3, and at the surface between Sites 2 and 4 (fig. 3C). Otherwise, there is a systematic distribution of aluminium across the other sites with only slight irregularities around Site 7. Development of the A_2 horizon is prominent across Sites 4, 5, 6 and 7, and accumulation of aluminium in the B horizon is evident at Sites 5 and 6, and to a lesser extent at Sites 2, 4 and 7.

Calcium

Apart from Site 1, relatively high calcium values occur near the ground surface, reflecting the distribution of organic matter in the soil profiles (fig. 3D). Below the near-surface accumulation calcium values are much lower, probably indicating an eluviated horizon (except at Site 7). On the other hand, development of an illuvial B horizon is not evident in the calcium distribution pattern. Relatively high calcium values at depth at Site 1, and somewhat lower concentrations at Site 3, probably represent unleached detrital shell carbonate. In contrast, this has been completely removed from the older soil profiles, except near the water table.

Magnesium

Concentrations of magnesium are low in all the Rheban soil profiles and the distribution pattern is uniform, with little evidence of near-surface accumulation (fig. 3E). As with the distribution of calcium, the pattern indicates an eluviated horizon low in acid-extractable magnesium, except for an anomaly associated with Site 7. Magnesium distribution appears little affected by local concentrations of shell or weatherable minerals.

Sodium

The analyses indicate that this cation is very regularly distributed across Rheban Spit, with a thin eluviated horizon present at Sites 5, 6 and 7

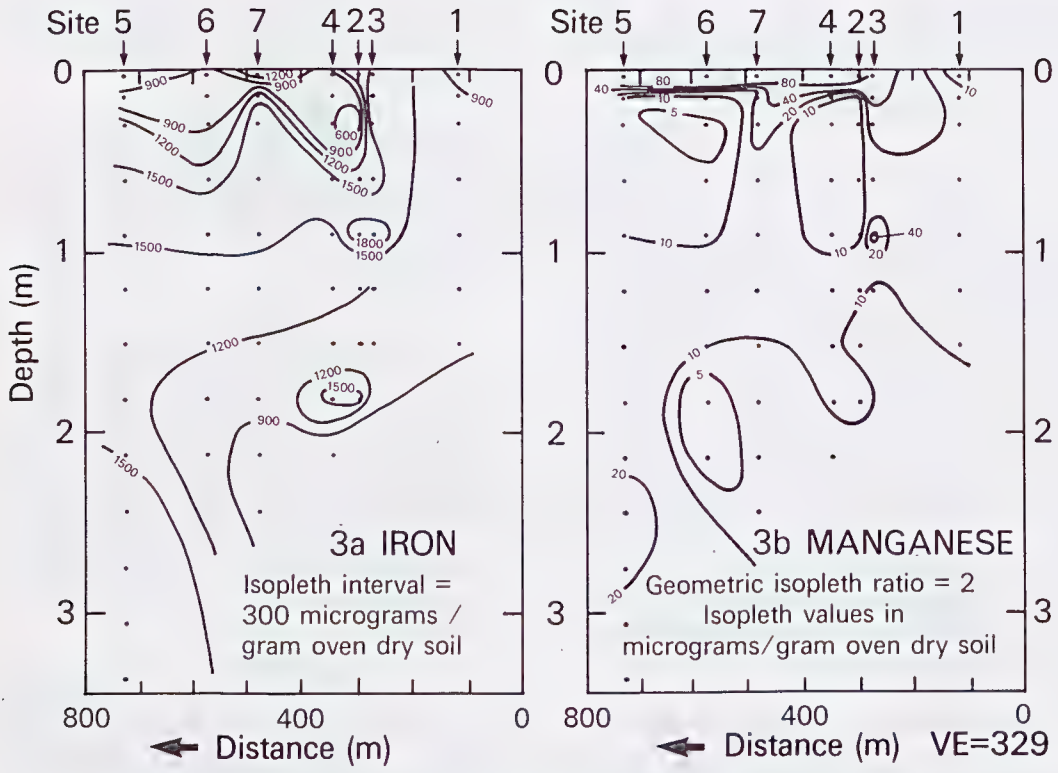
Site 5 6 7 4 2 3 1
Depth (m)
3a IRON
Isopleth interval = 300 micrograms / gram oven dry soil
3b MANGANESE
Geometric isopleth ratio = 2
Isopleth values in micrograms/gram oven dry soil
800 400 0
Distance (m)
VE=329

FIG.3 — Isograms showing distribution of acid-extractable iron, manganese, aluminium, calcium, magnesium and sodium in the Rheban soil profiles. Note different isopleth intervals and ratios.

(fig. 3F). Higher sodium concentrations occur in the lower parts of some profiles (reflecting saline groundwater) and irregularly down the Site 1 profile, probably as a result of high aerosol input of marine salt adjacent to Carrickfergus Bay (fig. 1).

DISCUSSION

Soil Classification

Using the Australian great soil group system to classify the Rheban soil profiles, the undifferentiated sediments at Site 1 constitute a "calcareous sand", but the profiles at all the other sites fall within the "podzol" great group (Stace *et al.* 1968). Insufficient data exist to satisfy the criteria for a spodic B horizon using the FAO-UNESCO (1974) classification. Therefore, none of the Rheban profiles may be classed as a "podzol" under this scheme; all are "arenosols". Thus, both great soil group classifications are relatively insensitive to the degree of development of the podzols at Rheban and do not adequately distinguish the profiles in terms of the established age sequence.

In contrast, the *Factual Key* of Northcote (1979) classifies the profiles into a developmental sequence which relates to soil age, even though the profiles all key into the coarse-textured subdivision of the "uniform" primary profile form (i.e. Uc: Northcote 1979). The undifferentiated sands at Site 1 (age = 0 years) are classed as a "calcareous sand" (principal profile form = Uc1.11), whereas the Site 3 profile (age = 3100 years) displays an incipient "bleached A_2 with colour B horizon" (Uc2.21). Sites 2, 4, 6 and 7 (all = 4 200 years) are also classed as "bleached sands with colour B horizons", but are grouped on the basis of their B horizon value/chroma ratings as Uc2.22. The Site 5 soil profile (age = 5 500 years) is also a "bleached sand", but is differentiated from the Uc2.22 profiles on the basis of the colour of the B horizon mottles (Uc2.23: Northcote 1979, Northcote *et al.* 1975).

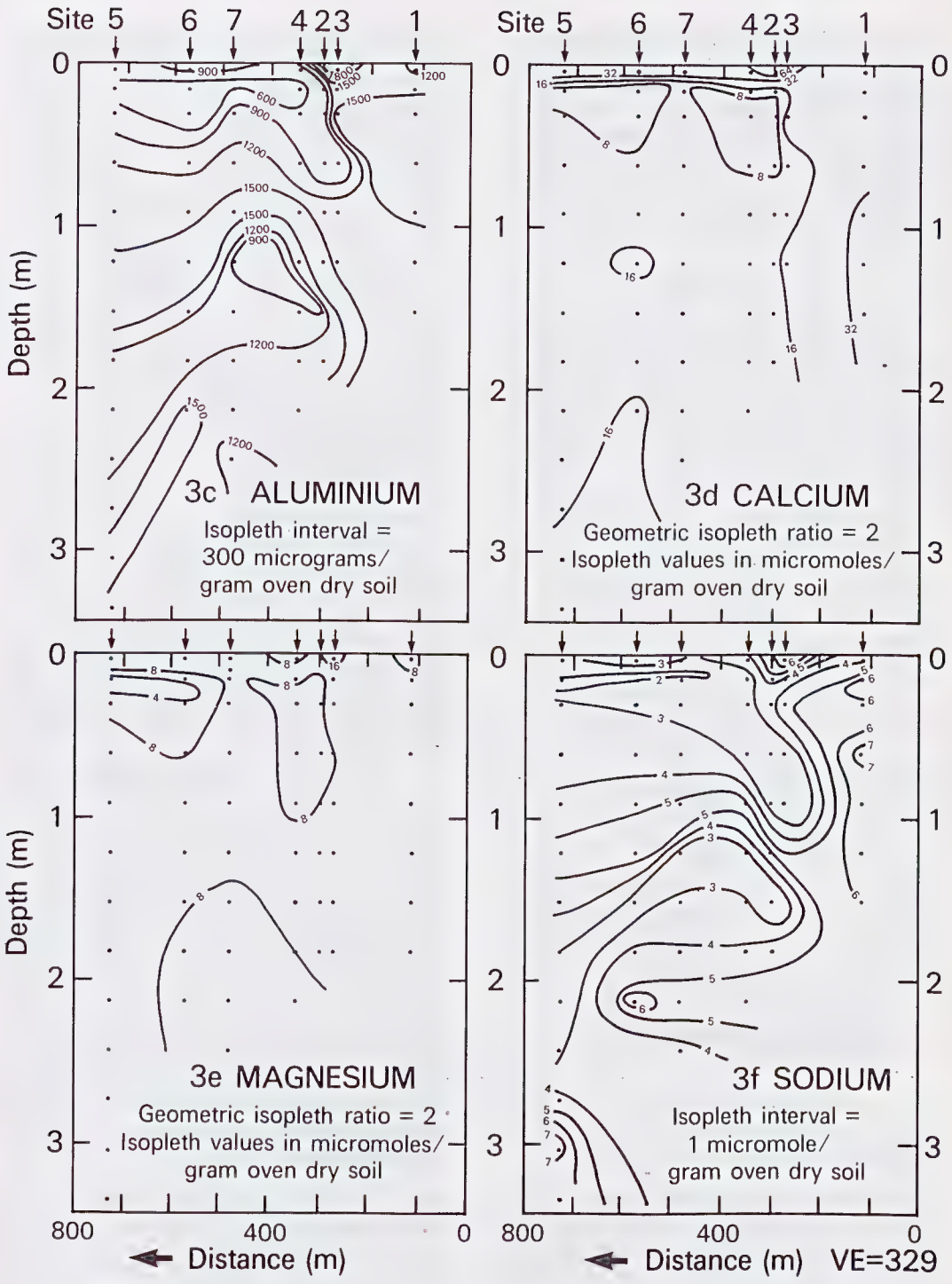
Site 5 6 7 4 2 3 1
Depth (m)
3c ALUMINIUM
Isopleth interval = 300 micrograms/ gram oven dry soil
3d CALCIUM
Geometric isopleth ratio = 2
Isopleth values in micromoles/ gram oven dry soil
3e MAGNESIUM
Geometric isopleth ratio = 2
Isopleth values in micromoles/ gram oven dry soil
3f SODIUM
Isopleth interval = 1 micromole/ gram oven dry soil
800 400 0
Distance (m)
VE=329

FIGURE 3 (cont.)

Insufficient chemical and micromorphological data are available to classify the Rheban soils adequately using the U.S. *Soil Taxonomy* (Soil Survey Staff 1975). However, from field observations and the analytical results presented above it seems unlikely that any of the Rheban soils would qualify as a "Spodosol", the *Soil Taxonomy* equivalent of a podzol (McKeague *et al.* 1983, Thompson & Hubble 1980).

Age Trends

The Rheban soil chronosequence and the age trends derived from it are based on four dated soil sites: a modern soil profile, two radiocarbon dated profiles and a composite soil profile consisting of averages obtained from the four soil profiles assigned identical ages in Part 1 of this study (Bowman 1986).

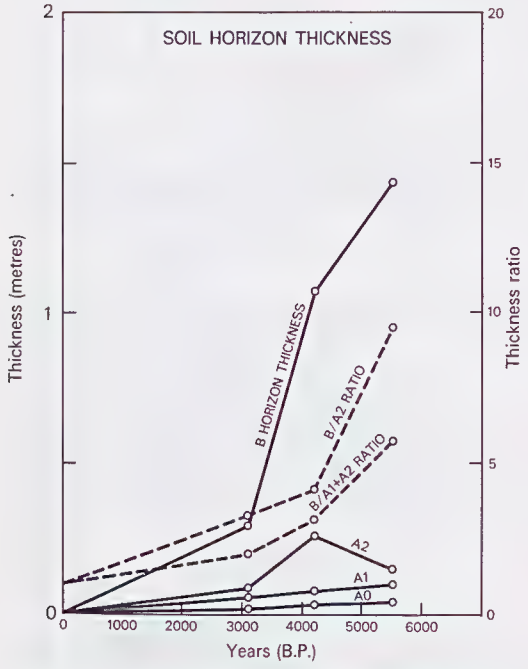

FIG.4 — Plot against soil age of horizon thickness and horizon thickness ratios for the Rheban profiles.

The profile morphology data in table 2 indicate that several progressive changes occur with increasing profile age. For example, some thickening is apparent in the A_1 and A_2 horizons, but this trend is slight in comparison with the pronounced development of the B horizon. Consequently, plots of horizon thickness ratios against age show a systematic increase if the B horizon is included (fig. 4), but not otherwise. Similar increases with age in the thickness of podzol horizons have been reported from chronosequences overseas (e.g. Jenny 1941, Olson 1958, Franzmeier & Whiteside 1963, Birkeland 1984, Rockwell *et al.* 1985) and from eastern Australia (Burges & Drover 1953, Thompson & Hubble 1980, Thompson 1981, Thompson & Bowman 1984, Bowman 1987).

The dominant colours of the Rheban profiles do not appear to change systematically with soil age. This differs from trends recorded in other chronosequences in which colour (particularly of the B horizon) was found to darken, deepen or redden with increasing soil age (e.g. Dickson & Crocker 1954, Brewer & Thompson 1980, Birkeland 1984, Thompson & Bowman 1984). Further analysis of the Rheban data to quantify better the contrast between the dominant colours of the A_0, A: and B horizons in terms of *colour distance units* (Bowman 1979) also failed to yield systematic age trends similar to those obtained from a comparable podzol chronosequence in New South Wales (Bowman 1987). Also, the ubiquitous gradational-even A:-B horizon transition in the Rheban profiles contrasts with observations on the mainland (Bowman 1979, Thompson & Bowman 1984), where coastal podzols older than 4500 years invariably display sharp-irregular A:-B horizon boundary configurations.

However, the pH data from Rheban do yield systematic age trends, with horizon pH and average profile pH tending to decrease with age (fig. 5). The B horizon trend is in good agreement with that obtained for New South Wales podzols, but the pH values of the C horizon are somewhat lower than the corresponding figures for New South Wales (fig. 5). This decrease in soil pH with increasing age has been reported in many chronosequence studies of young, freely-drained soils (e.g. Salisbury 1925, Hissink 1938, Crocker & Major 1955, Olson 1958, Franzmeier *et al.* 1963, Stevens & Walker 1970). The age trend relates to the build-up of organic matter and the production of humic and fulvic acids, resulting in the progressive leaching of carbonate (where present) and mobile bases (Stevens & Walker 1970).

The lack of detrital shell in all the Rheban profiles except Site 1, probably indicates extensive leaching from the older sand deposits. Hence, the complete removal of visible shell from the sediment at Site 3 during the 3100 years since its deposition, provides a measure of the maximum time required for complete carbonate leaching at Rheban. As

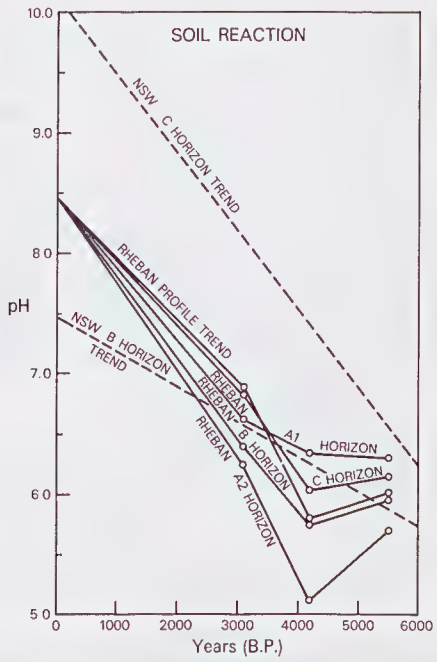

FIG.5 — Soil age:pH plots of average profile pH and horizon pH for Rheban and New South Wales podzols. Origin of Rheban graphs is mean of pH values for Site 1 (= 0 years). Rheban profile trend derived from mean pH of samples from each site. New South Wales regression trends in figures 5, 6, 7 and 8 from Bowman (1987).

Thompson & Bowman (1984) noted, the rate of removal of shell carbonate largely depends on the initial size of fragments and will vary locally. However, rates determined in comparable chronosequence studies using better short-term age control do accord with the Rheban estimate (e.g. Olson 1958).

There is good agreement between the age trend for B horizon organic matter content in the Rheban chronosequence and in New South Wales coastal podzols (fig. 6; Bowman 1987). Other measures of organic matter content in the Rheban profiles also increase with age (notably the A_1 horizon content: fig. 6), indicating accumulation of organic matter in the chronosequence. This agrees with northern hemisphere observations, and there is some evidence from Rheban for attainment of a "steady state" situation in organic matter gains and losses, as suggested by studies overseas (e.g. Crocker & Dickson 1957, Jacobson & Birks 1980, Jenny 1980, Ellis & Richards 1985).

Systematic age trends are evident in the concentrations in the Rheban samples of some acid-extractable elements. Extractable aluminium in the A_2 horizon progressively decreases with time, whereas in the B horizon it increases (fig. 7). Hence, the B/A_2 ratio for aluminium rises with increasing profile age, reflecting progressive soil development and chemical differentiation of podzol horizons. However, the *mean* aluminium concentration in the Rheban profiles decreases with age (fig. 7), indicating net loss of this cation from the soil. These trends are in agreement with New South Wales results, but the B horizon concentrations of aluminium at Rheban are substantially higher than the corresponding New South Wales averages, probably reflecting differences in parent material rather than organic matter accumulation.

Consistent age trends are not immediately evident in the distribution of acid-extractable iron in the Rheban chronosequence, mainly because the values for this cation are anomalously high in all horizons at Site 3 (fig. 8). This could be attributed to the pedogenic effects of the comparatively low topographic position of Site 3 (and hence relatively high water table) causing apparent compression of the soil profile (Thompson & Hubble 1980). However, if horizon concentration ratios for iron are examined, the B/A_2 ratio (for example) shows a consistent increase with age and is accordant with the B/A_2 age trend for New South Wales coastal podzols (fig. 8 and Bowman 1987).

The progressive leaching of both calcium and sodium from the Rheban chronosequence is evident in a plot against age of the average profile concentration of these cations (fig. 9). While this trend is the same as that observed in New South Wales podzols, the increase in calcium in the A_1 horizon at Rheban with increasing soil age (fig. 9) is the reverse of the New South Wales trend (Thompson & Bowman 1984, Bowman 1987). In addition, no manganese or magnesium age trends were identified in the Rheban chronosequence, although such trends have been recognized in New South Wales (Bowman 1979).

CONCLUSION

A soil chronosequence of four ages and four stages of development ranging from calcareous sands to podzols has evolved in the sediments of Rheban Spit. Classification of the profiles according to the Australian great soil groups (Stace *et al.* 1968) does not effectively separate the soils on the basis of age: this is better achieved by *A Factual Key* (Northcote 1979).

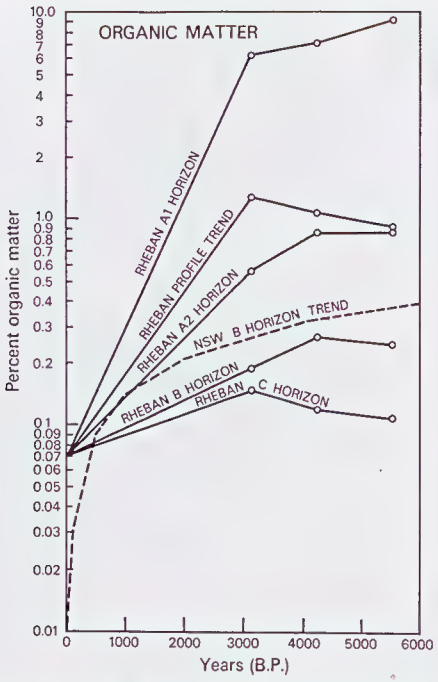

FIG.6 — Plot of organic matter content against soil age for Rheban and New South Wales profiles. Note: log scale used on the ordinate.

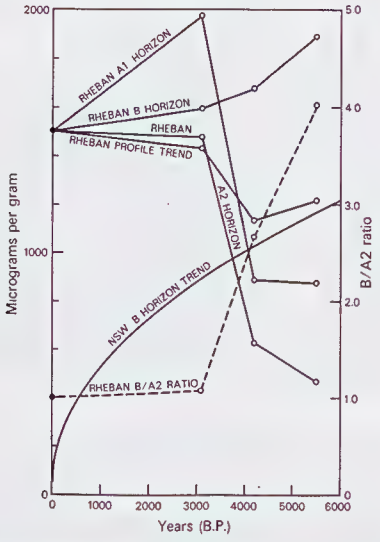

FIG.7 — Plot of acid-extractable aluminium against soil age for Rheban and New South Wales profiles. Origin of Rheban graphs is mean aluminium concentration in Site 1 samples. Rheban B/A_2 ratio refers to the ratio of acid-extractable aluminium in those horizons.

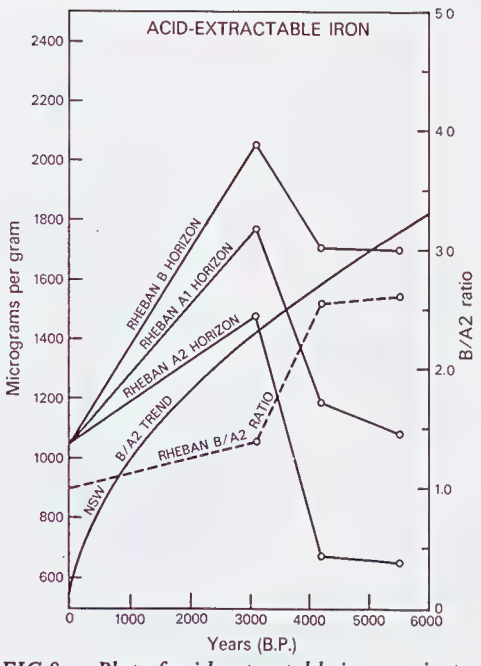

FIG.8 — Plot of acid-extractable iron against soil age for Rheban and New South Wales profiles. Origin of Rheban graphs is mean iron concentration in Site 1 samples. Rheban B/A_2 ratio refers to the ratio of acid-extractable aluminium in those horizons.

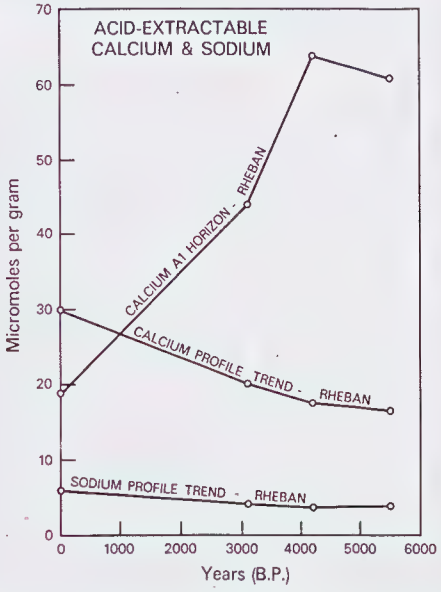

FIG.9 — Plot of acid-extractable calcium and sodium against soil age for Rheban soils.

Age trends are evident in a range of soil features recorded and measured in the Rheban soils. The most prominent of these are the leaching of marine shell carbonate, the accumulation of organic matter in the soils, the acidification of the profiles, the mobilisation of several acid-extractable elements and the thickening of the B horizon with increasing soil age. The soil horizons have become increasingly differentiated in terms of iron and aluminium distribution, while the average content of these elements in the profiles has decreased. In general, the age trends are in accord with those evident in a comparable podzol chronosequence in New South Wales and with similar overseas studies.

ACKNOWLEDGEMENTS

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(accepted 3 March 1987)

PLEISTOCENE MACRO- AND MICRO-PLANT FOSSILS FROM ROSEBERY, WESTERN TASMANIA

by Eric A. Colhoun and Guus van de Geer

(with one table and one plate)

COLHOUN, E.A. & VAN DE GEER, G., 1987 (30:vi): Pleistocene macro- and micro-plant fossils from Rosebery, western Tasmania. *Pap. Proc. R. Soc. Tasm.*, 121: 89-92. ISSN 0080-4703. Department of Geography, University of Newcastle, N.S.W. 2083 (E.A.C.); and Department of Geography, University of Tasmania, G.P.O. Box 252C, Tasmania 7001.

Fossils of *Microstrobos niphophilus* and pollen in glacial lake clays that underlie till of the Penultimate Glaciation of western Tasmania indicate that an alpine heathland-herbfield environment occurred at 200 to 240 m altitude, and that the temperature was at least 4.5 to 5° C colder than at present. Charcoal in the deposits indicates that fires occurred adjacent to ice long before Man arrived in Tasmania.
Key Words: Pleistocene, western Tasmania, alpine heathland/herbfield, *Microstrobos*, fire, lower temperature.

INTRODUCTION

During a visit to the Rosebery open cut mine while examining glacial deposits in January 1987 abundant, small wood and charcoal fragments were found in glacial lake clays. The occurrence of such fragments in glacial lake clay deposits is extremely rare in Tasmania. Although transported into the lake the fragments were so well preserved and so numerous that they could not have travelled far. The abundance of wood suggested that the glacial lake clays might contain pollen from which the vegetation and climate that occurred in the area at the time of their deposition might be interpreted. This paper presents and interprets the results.

OCCURRENCE

The Rosebery open cut mine is located between 200 and 240 m a.s.l. on the southwestern slope of Mount Black just north of the Rosebery township (Grid Ref. 787741 on Sophia Sheet 8014, 3rd edition, 1977, 1:100 000 Topographic Survey Map).

A section on the northern wall of the upper level of the mine showed 1-2.5 m of varved-type glacial lake silt and clay resting on an irregular surface of black slates of the Cambrian age Rosebery Group (Corbett *et al.* 1977). The lake deposits extended for about 8 m and were overlain by more than 2 m of compact basal till deposits that were formed during the Boco Glaciation, the Penultimate Glaciation of western Tasmania (Augustinus & Colhoun 1986).

FOSSILS

The macrofossils consisted of many wood fragments 50 to 300 mm in length and 3 to 20 mm in thickness. Most were twisted in a manner which indicated that they were probably derived from a low or reptant shrub. Two branchlets were found which bore the typical leaf form of *Microstrobos niphophilus* Garden and Johnson. The field identification was confirmed under the SEM by R.S. Hill of the Botany Department, University of Tasmania (plate 1). In addition, one broken branchlet that was probably *Diselma archeri* Hook but might have been *Microcachrys tetragona* Hook was found.

The macrofossil evidence suggests that a thicket of low alpine shrubs grew on the southern slopes of Mount Black just before the arrival of the ice which moved from east to west in the Rosebery area. The ice would have destroyed the vegetation and its meltwaters would have washed the branchlets into the pond in which the silt and clay was accumulating before it advanced over the deposit.

A sample of clay was processed for pollen using the extraction method of Faegri & Iversen (1975). The pollen taxa were identified from modern reference slides prepared by M.K. Macphail in 1969-1972 and were allocated to plant taxa following the nomenclature of Curtis (1963, 1967) and Curtis & Morris (1975). The percentages of pollen recorded are calculated from a sum of 337 grains of tree, shrub and dry-land taxa (table 1).

The pollen assemblage is typical of assemblages that have been recorded from non-forested environments in western Tasmania during times

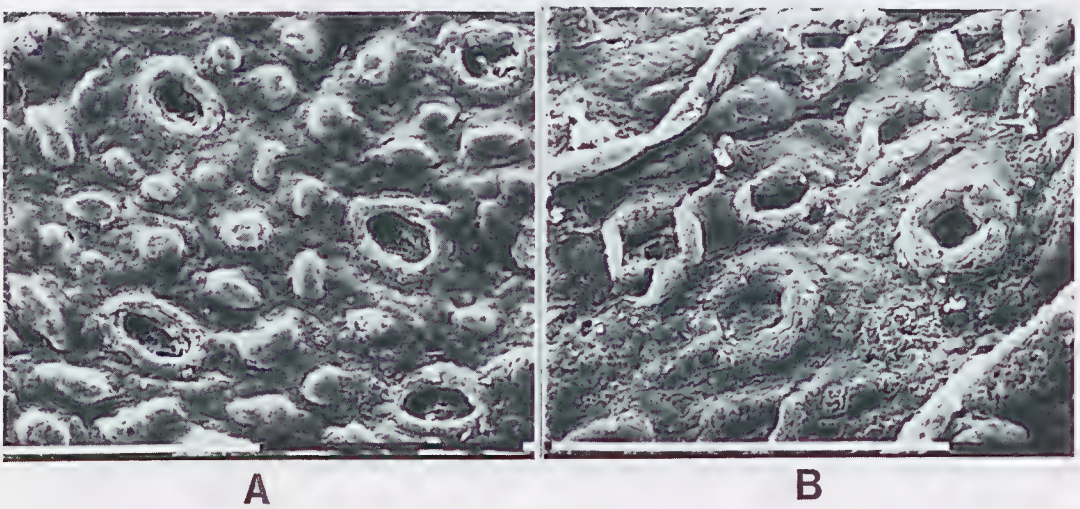

PLATE 1 — Scanning electron micrographs. A, fossil Microstrobos *cuticle; B, fossil cuticle, probably* Diselma, *possibly* Microcachrys. *In both cases scale unit* = 100μm. *Photographs per courtesy of Dr R.S. Hill.*

when ice was present in the mountains and the lowland climate was cold. The assemblage is dominated by herbs particularly grasses and Compositae, with small amounts of *Plantago*, *Gentianella* and *Oreomyrrhis* which are usually recorded in alpine assemblages. The relatively high values for alpine-subalpine shrubs including *Microstrobos*, *Diselma* and *Microcachrys*, plus the high shrub values particularly of Epacridaceae T-type, indicates the presence of alpine and subalpine heath communities. The low percentage of tree pollen and very low percentage of rainforest tree types (many of which could have survived in shrub form) suggest that only scattered shrubs and small trees occurred within the wet alpine-subalpine heathland-herbfield communities which occurred at or above the equivalent altitude of modern treeline.

The lake deposits and pollen preparations contains abundant finely divided charcoal fragments. The charcoal indicates that natural burning of the vegetation occurred in close juxtaposition to the advancing glaciers at a time which greatly preceded the advent of Man to Tasmania about 20 000 yr b.p. (Kiernan *et al.* 1983).

SIGNIFICANCE

The Rosebery site is significant for several reasons. Firstly, it is the only site known from the lowland temperate forest country of western Tasmania where macrofossils of *Microstrobos* and microfossils that indicate an alpine floral assemblage are associated with glacial deposits that precede in stratigraphic age the Last Glacial Stage. Secondly, because the lake deposits are clearly overlain by till deposits of the Boco glaciation, which in the Mackintosh Valley have been radiocarbon dated to more than 43 800 yr b.p. (SUA 1047), they are most unlikely to have been formed during the middle of the Last Glacial Stage (25 000–50 000 yr b.p.) when deposits that contain similar pollen assemblages were formed at Henty Bridge, Tullabardine Dam, and Newall Creek (Colhoun 1985a, Colhoun & van de Geer 1986, van de Geer *et al.* unpublished). It is notable that the assemblage at Rosebery contains only pollen that could be derived from the modern subalpine-alpine vegetation of the West Coast Ranges above 1000 m and does not contain any ancient types with Tertiary affinities. Thus, although stratigraphically and radiometrically dated as preceding the Last or

TABLE 1

Percentages of pollen taxa recorded.

Temperate rainforest trees	2.7	
Lagarostrobos franklinii		0.6
Nothofagus cunninghamii		1.8
Phyllocladus aspleniifolius		0.3
Other trees	11.3	
Acacia		0.6
Casuarina		3.6
Eucalyptus		7.1
Small trees and shrubs	17.6	
Boronia		0.3
Coprosma		0.6
Epacridaceae T-type		10.7
Epacridaceae *Monotoca*		0.3
Hakea		0.3
Letospermum		0.6
Melaleuca		0.9
Orites		2.4
Indeterminate Proteaceae, probably small		1.2
Tasmannia lanceolata		0.3
Alpine-subalpine shrubs	12.0	
Athrotaxis-Diselma archeri type		2.1
Belendena montana		0.3
Microcachrys tetragona		3.0
Microstrobos niphophilus		6.0
Podocarpus lawrenceii		0.6
Herbs	57.6	
Chenopodiaceae		3.0
Compositae Tubuliflorae		24.0
Cruciferae		1.2
Gentianella		0.3
Gramineae		25.5
Labiatae		0.3
Liliaceae		0.3
Plantago		1.2
Umbelliferae		0.9
Oreomyrrhis		0.9
Outside Percentage Sum		
Sedges	7.1	
Cyperaceae		5.3
Restionaceae		1.8
Aquatics	0.6	
Neopaxia		0.3
Myriophyllum		0.3
Fern spores	6.6	
Monolete		1.8
Gleichenia		3.6
Trilete		1.2
Lycopodiaceae	15.8	
Lycopodium australianum		1.5
L. fastigiatum		9.8
L. scariosum		4.5

Margaret Glaciation of the West Coast Range (Colhoun 1985b) the deposit cannot be very old which is consistent with the interpretation of a Penultimate Glaciation age.

The occurrence of the *Microstrobos* macrofossils at 200-240 m can be compared to the distribution of the same taxon today at over 1000 m altitude in the West Coast Range. Such altitude difference implies a minimum temperature reduction of about 4.5 to 5° C compared with present (mean annual temperature, 11° C). The temperature depression is also comparable with that estimated for the period (35 000-25 000 yr b.p.) that immediately preceded the maximum of the Last or Margaret Glaciation as recorded at Henty Bridge (5° C) (Colhoun 1985a) and Tullabardine Dam (3.5 to 4.5° C) (Colhoun & van de Geer 1986).

ACKNOWLEDGEMENT

The authors acknowledge the cooperation of the Geology Section, Rosebery Mine.

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VAN DE GEER, G., FITZSIMONS, S.J. & COLHOUN, E.A., unpublished: Holocene to Middle Last Glaciation vegetation history and palaeoclimate at Newall Creek, western Tasmania.

(accepted 24 March 1987)

REGENERATION CHARACTERISTICS OF A SWAMP FOREST IN NORTHWESTERN TASMANIA

by N. Gibson, K. Williams, J. Marsden-Smedley and M.J. Brown

(with one table and five text-figures)

GIBSON, N., WILLIAMS, K., MARSDEN-SMEDLEY, J. & BROWN, M.J., 1987 (30:vi): Regeneration characteristics of a swamp forest in northwestern Tasmania. *Pap. Proc. R. Soc. Tasm.*, 121: 93-100. ISSN 0080-4703. National Parks and Wildlife Service, P.O. Box 210, Sandy Bay, Tasmania 7005; and Forestry Commission, 199 Macquarie Street, Hobart, Tasmania 7000 (MJB).

The botanical composition and regeneration characteristics are described for a *Melaleuca ericifolia-Leptospermum lanigerum* forest from northwestern Tasmania. The size classes of the two dominant species are highly correlated with tree age. Size class analysis shows that the dominants are regenerating continuously. The relationship of this forest type to rainforest and wet sclerophyll forest are discussed.
Key Words: Tasmania, swamp forest, regeneration, *Melaleuca, Leptospermum*

INTRODUCTION

The forests of Tasmania traditionally are treated at the formation level as either sclerophyll forest or as rainforest (e.g. Jackson 1965, Curtis 1965-66, Gilbert 1970-71). The sclerophyll forests are broken into two classes, wet and dry sclerophyll, each of which has a characteristic understorey flora. The dry sclerophyll forests are dominated by either *Eucalyptus* or *Casuarina* (Duncan & Brown 1985), whilst wet sclerophyll forests are *Eucalyptus*-dominated. The dominant species of the two sub-formations have quite different regeneration modes, with dry sclerophyll dominants being either continuous or pulse regenerators while most wet sclerophyll forests are either even-aged or contain only a few age-classes, depending on the past history of fires.

Jarman & Brown (1983) have defined cool temperate rainforest in Tasmania as those forest communities dominated by species of *Nothofagus*, *Atherosperma*, *Eucryphia*, *Athrotaxis*, *Lagarostrobos*, *Phyllocladus* or *Diselma* of at least 8 m in height. Rainforest species are defined as those species able to perpetuate themselves (either vegetatively or from seed) within forests dominated by one or more of the species listed above.

In northwestern Tasmania there are large tracts of closed swamp forest which are usually dominated by *Acacia melanoxylon* or *Melaleuca ericifolia* (Kirkpatrick & Dickinson 1984, fig. 1). These forests subsume a range of community types from almost pure *A. melanoxylon* forests through *A. melanoxylon*-Myrtaceae-*Nothofagus*(-*Phyllocladus*) dominated forests to almost pure *Leptospermum* and/or *Melaleuca* forest (Anon. 1982; Jarman & Brown 1983, Jarman *et al.* 1984, R. Mesibov *pers. comm.* 1986).

Jarman & Brown (1983) considered that whilst *Leptospermum lanigerum*, *L. nitidum*, *L. scoparium* and *Melaleuca squarrosa* may be found in the rainforest canopy, they were doubtful rainforest species, and suggested that detailed studies were required to determine their status. Thus Jarman *et al.* (1984) point out that the niche occupied in rainforest by these myrtaceous species may be that of a "good" rainforest species or may instead be similar to that filled by *Eucalyptus* in the mixed forests of Gilbert (1959).

The relationships of the swamp forests to either rainforests or to sclerophyll forests have not been determined. The floristic variation they contain apparently ranges from predominantly rainforest elements to predominantly sclerophyllous and the regeneration characteristics of the non-eucalypt dominants have not been described. The aim of the present paper is to provide a floristic description of one such swamp forest and to investigate the regeneration strategies of the two forest dominants — *Leptospermum lanigerum* and *Melaleuca ericifolia*.

THE STUDY AREA

The study area is located on the Welcome River in the far northwest of the State. This area lies in the warm-humid climatic zone (Gentilli 1972) with a winter rainfall maximum. The swamp

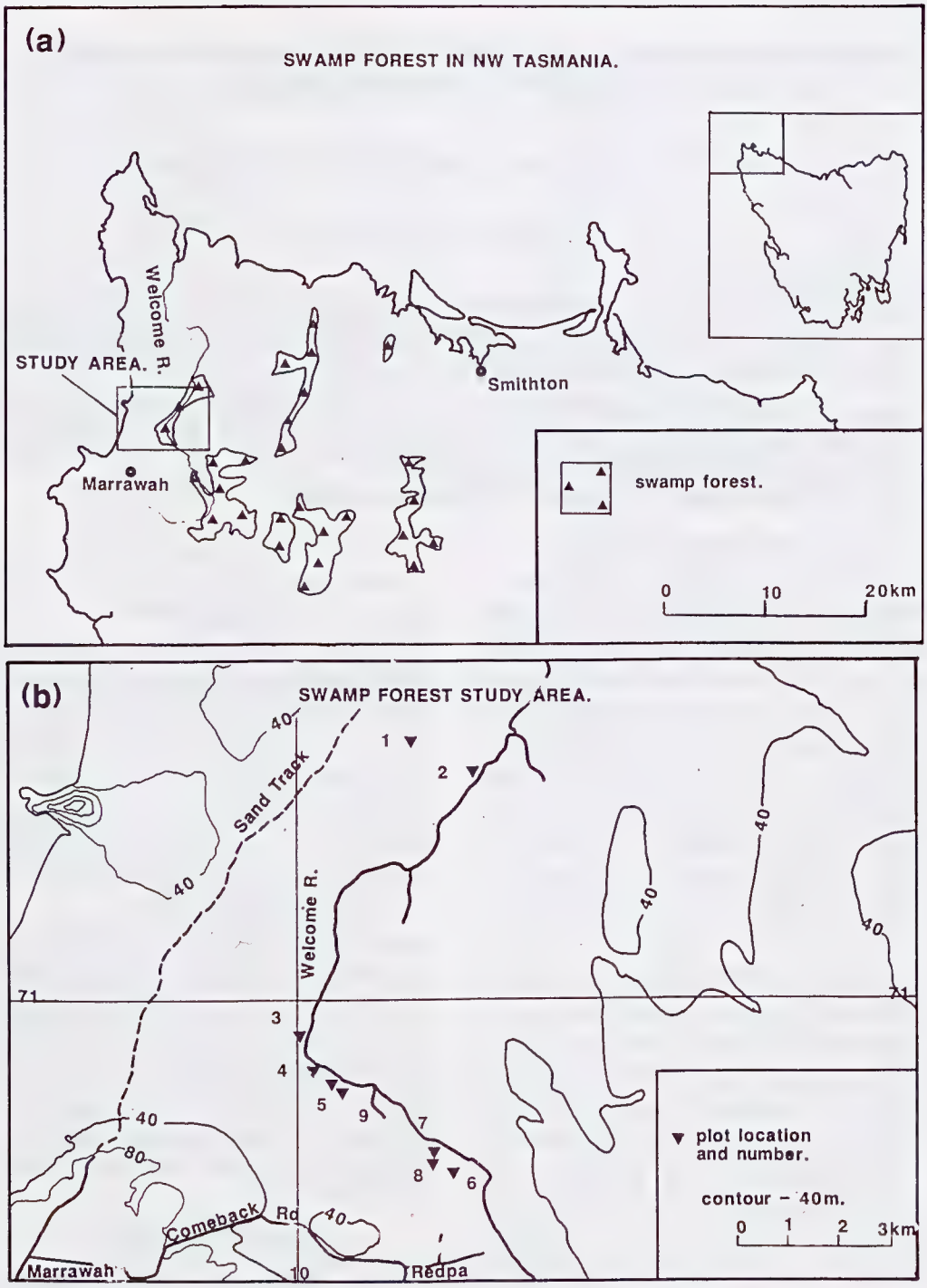

FIG.1 — (a) The occurrence of swamp forest in northwestern Tasmania (after Kirkpatrick & Dickinson 1984), and (b) the location of the study area.

forests of this area are commonly inundated in the winter months.

The topography is of a broad flat valley, the vegetation being underlain by Holocene alluvium, sand and gravel. The swamp forest in the area is dominated by *Melaleuca ericifolia* with *Leptospermum lanigerum* also being present.

METHODS

Vegetation data were collected from nine plots along the Welcome River between Redpa and Boggy Creek. Both structural and floristic data were recorded from 20 m diameter plots using the TASFORHAB system of Peters (1984). From these data a vegetation description was compiled and a generalized vegetation profile was constructed.

In the area presently being cleared to make drainage channels, 49 basal slabs of *Melaleuca ericifolia* from 10 to 460 mm diameter were collected for ageing of the trees. Nine slabs of *Leptospermum lanigerum* from 10 to 600 mm diameter were also collected. Slab diameters were determined with a diameter tape and ring counts were made on their planed tops. From these data a simple linear regression was made between age and size. Size-class analyses were undertaken from six sites. At each site, a 10 × 10 m plot was established and all individuals greater than 100 mm diameter were counted and diameters at breast height (DBH) recorded. A 5 × 5 m subplot was located in one corner of the plot and all individuals less than 100 mm diameter were counted. Size class histograms were constructed from these data.

The size distributions were then modelled against the power function $y = y_o x^{-b}$ and the negative exponential $y = y_o e^{-bx}$, where y is the number of individuals in size class x, y_o is the initial population size and b is mortality. The power function is appropriate to forest stands in which there is continuous regeneration with a mortality that decreases with increasing age, whilst the negative exponential reflects constant mortality (Hett & Loucks 1976). These models were tested for the four plots of *Melaleuca ericifolia* for which data were available in at least five size classes.

As a further check on the regeneration mode of the two species, increment counts were made from rings near the centre and at the outside of stem slabs. These measurements were made to determine whether there was any indication that episodic release from suppression of more or less even-aged stems was giving rise to apparent continual regeneration.

Nomenclature follows Curtis (1963, 1967), Curtis & Morris (1975), Willis (1970), and Jones & Clemesha (1981).

RESULTS

Vegetation

The vegetation of the area is dominated by a closed canopy of *Melaleuca ericifolia* with *Acacia melanoxylon* and *Leptospermum lanigerum* as sub-dominants. The canopy also contains occasional individual trees of *Eucalyptus ovata* and *E. obliqua* on better-drained sites. The understorey is dominated by *Melaleuca ericifolia* with *Coprosma quadrifida*, *Drimys lanceolata*, *Leptospermum lanigerum* and occasionally *Pomaderris apetala*, again on better drained sites. The ground layer contains *Gahnia grandis* and *Lepidosperma elatius* together with the ferns *Polystichum proliferum*, *Blechnum nudum* and *Dicksonia antarctica*. Epiphytic ferns, including *Microsorium diversifolium*, *Hymenophyllum peltatum*, *Ctenopteris heterophylla* and *Grammitis billardieri* were occasionally present. A generalized vegetation profile is shown in figure 2. At the time of sampling (June) the free water surface was at or above ground level in most of the area traversed.

Regeneration Modes of the Dominant Species

A highly significant correlation was found between diameter and age for both *Melaleuca ericifolia* and *Leptospermum lanigerum* (figs 3 and 4). Thus size of stem provides a reasonable means of estimating age. Examination of the incremental growth of individual stems indicated that considerable suppression of individuals was occurring through the stand, but there was no indication that the initial regeneration resulted from a single disturbance event, nor that the release of individuals was tied to some broad scale disturbance such as fire or windthrow. Thus size class analysis can be used to describe adequately the population dynamics of those samples for which data are available. In all of the plots, there were large numbers of seedlings and saplings (individuals less than 100 mm diameter) found under closed canopies (fig. 5). In plots 1, 2, 3 and 5, size class distributions fitted the power function model (table 1).

DISCUSSION

The occurrence of large numbers of seedlings and saplings scattered through the forest suggests

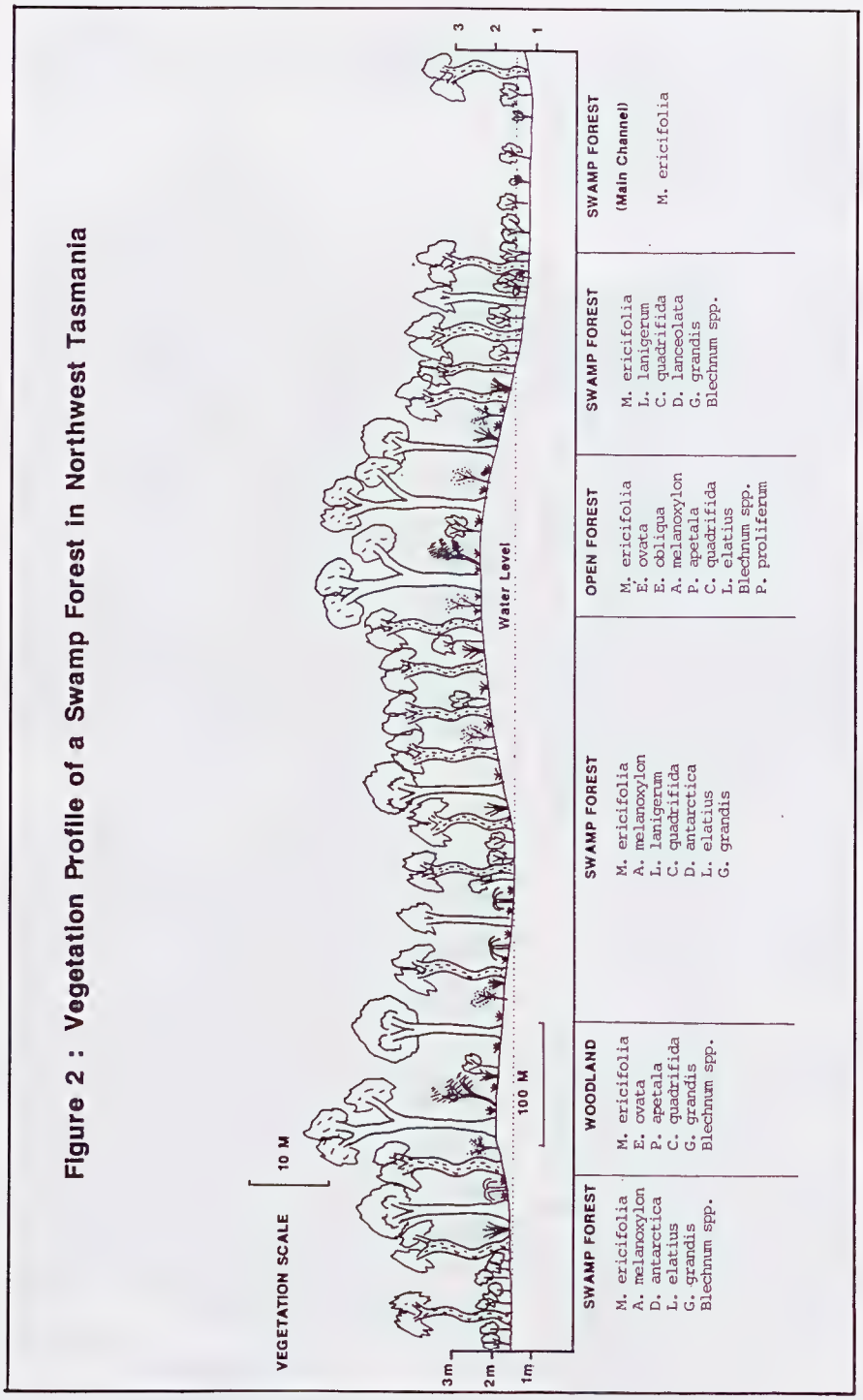

FIG.2 — Vegetation profile of a swamp forest in northwestern Tasmania.

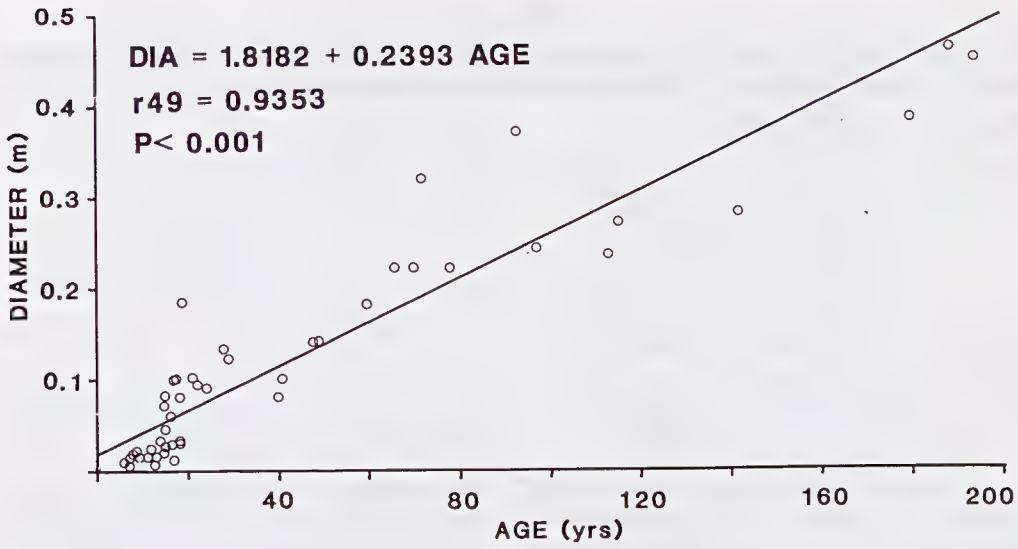

FIG.3 — Regression of diameter on age for Melaleuca ericifolia.

that *Melaleuca ericifolia* is capable of continuous regeneration in an essentially closed-canopy forest. This observation is confirmed by the age and size class analyses and the fit to the power function. However, although there is a highly significant correlation of size and age, it is apparent from the increment counts that growth rates are variable and that suppression can occur for periods in excess of 20 years. Further analyses of the pattern

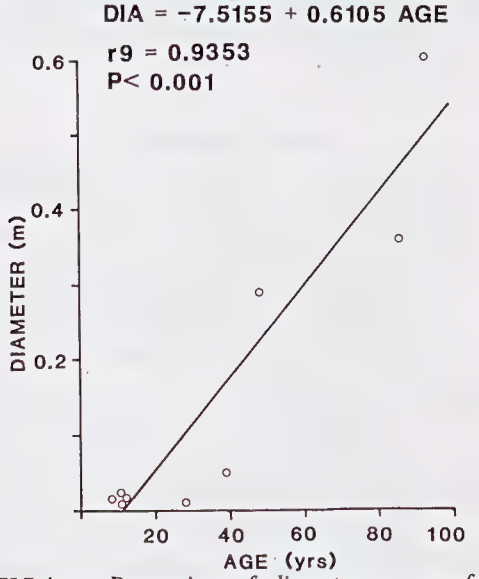

FIG.4 — Regression of diameter on age for Leptospermum lanigerum.

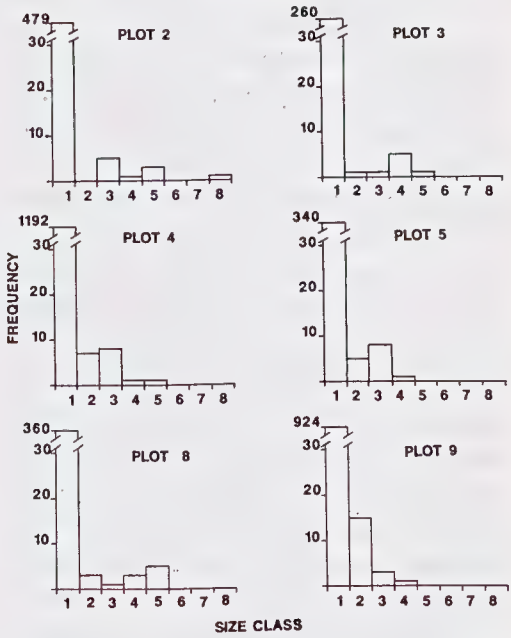

FIG.5 — Frequency-size class distributions for Melaleuca ericifolia *from six sample plots. Stems grouped into 100 mm size classes.*

TABLE 1

Size class (x) and frequency (y) relationships for four samples taken within the *Melaleuca ericifolia* swamp forest. (a) Exponential function, (b) Power function.

Sample no.	Relationship	r	P
1	(a) ln(y+1) = 38.411-0.513x	-0.608	
	(b) ln(y+1) = 20.796-1.277ln x	-0.633	<0.05
2	(a) ln(y+1) = 88.269-0.864x	-0.648	
	(b) ln(y+1) = 67.997-2.347ln x	-0.762	<0.05
3	(a) ln(y+1) = 897.823-1.417x	-0.850	<0.05
	(b) ln(y+1) = 488.947-3.720ln x	-0.920	<0.01
4	(a) ln(y+1) = 111.756-0.848x-	0.634	
	(b) ln(y+1) = 108.400-2.566ln x	-0.783	<0.05

of occurrence of seedlings in relation to tree death and canopy gaps would be necessary to determine absolutely whether the observed release from suppression is light (cf. Duncan 1981, Ogden 1985, Read & Hill 1985) or moisture-related (cf. Bowman & Kirkpatrick 1986). However, regenerating seedlings and saplings of *Leptospermum lanigerum* were always present in higher numbers than *Melaleuca ericifolia* under canopy gaps and adjacent to forest edges.

The goodness-of-fit to the power function model suggests that highest mortality occurs in the smaller size classes, but once stems are larger than about 100-200 mm DBH, there is a high probability that they will grow through to old age (i.e. in excess of 200 years). Less data are available for *Leptospermum lanigerum*, but it also appears to have a linear size-age relationship.

The oldest trees in this forest are approximately 200 years old. The age to senescence of *Melaleuca ericifolia* (and of *Leptospermum lanigerum*) is unknown but species of both *Melaleuca* and *Leptospermum* are found as codominants in rainforests (e.g. Jarman & Crowden 1978, Jarman *et al.* 1984), some of which are known to be at least 300 years old (e.g. Brown & Podger 1982). Elsewhere in the northwestern region, these species occur in swamp forests together with *Nothofagus*, *Phyllocladus* and such rainforest understorey shrub species as *Trochocarpa cunninghamii* and *Anopterus glandulosus* (Anon. 1982), and the whole of the region is climatically suited to the growth of rainforest (Jackson 1965).

Thus there may be a seral and/or successional relationship in which these relatively young Myrtaceae-dominated forests are eventually replaced by forests containing the more usual rainforest dominants. However there is no evidence in the present case of colonization by any rainforest species *sensu* Jarman & Brown (1983) (see appendix). An alternative interpretation is that the *Melaleuca* (and/or *Acacia melanoxylon*) swamp forests represent a deflected climax vegetation, whose occurrence is related to the poor drainage and longevity of seasonal inundation. Further work is necessary to determine whether *Melaleuca*/*Leptospermum* are able to grow in periodically anoxic conditions which may limit the growth of *Nothofagus* and *Phyllocladus*. Until such work is undertaken, it is not possible to determine whether *Melaleuca ericifolia* or *Leptospermum lanigerum* in these swamp forests are behaving as "good" rainforest species (cf. Jarman *et al.* 1984).

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(accepted 17 March 1987)

APPENDIX

Check-list of vascular plants found in the *Melaleuca ericifolia* swampforest.

PTERIDOPHYTA

Aspidiaceae
Polystichum proliferum

Blechnaceae
Blechnum nudum
Blechnum wattsii

Dennstaedtiaceae
Histiopteris incisa
Hypolepis rugosula

Dicksoniaceae
Dicksonia antarctica

Grammitidaceae
Ctenopteris heterophylla
Grammitis billardieri

Hymenophyllaceae
Hymenophyllum peltatum
Hymenophyllum sp.

Polypodiaceae
Microsorium diversifolium

ANGIOSPERMAE: DICOTYLEDONEAE

Apiaceae
Hydrocotyle javanica

Apocynaceae
Parsonsia straminea

Asteraceae
Cirsium sp.
Helichrysum dendroideum
Senecio sp.

Brassicaceae
Brassica sp.
Cardamine heterophylla

Elaeocarpaceae
Aristotelia peduncularis

Mimosaceae
Acacia melanoxylon

Myrtaceae
Eucalyptus obliqua
E. ovata
Leptospermum lanigerum
Melaleuca ericifolia
M. squarrosa

Onagraceae
Epilobium hirtigerum

Oxalidaceae
Oxalis corniculata

Pittosporaceae
Billardiera longiflora

Polygonaceae
Muehlenbeckia gunnii

Ranunculaceae
Clematis aristata
Ranunculus sp.

Rhamnaceae
Pomaderris apetala

Rosaceae
Acaena novae-zelandiae

Rubiaceae
Coprosma quadrifida

Thymelaeaceae
Pimelea drupacea

Winteraceae
Drimys lanceolata

ANGIOSPERMAE: MONOCOTYLEDONEAE

Cyperaceae
Carex appressa
Gahnia grandis
Lepidosperma elatius
Schoenus maschalinus
Scirpus fluitans

Juncaceae
Juncus effusus

GENE FLOW BETWEEN THREE EUCALYPT SPECIES AT SNUG PLAINS

by N.J. Davidson, J.B. Reid and B.M. Potts

(with two tables and eight text-figures)

DAVIDSON N.J., REID, J.B. & POTTS B.M., 1987 (30:vi): Gene flow between three eucalypt species at Snug Plains. *Pap. Proc. R. Soc. Tasm.*, 121: 101-108. ISSN 0080-4703. Department of Botany, University of Tasmania, Hobart, Tasmania, Australia 7001.

The extent of hybridisation and gene flow between the three *Monocalyptus* species, *Eucalyptus pulchella*, *E. coccifera* (series *Piperitae*) and *E. delegatensis* (series *Obliquae*) at Snug Plains (600 m) in southeastern Tasmania was examined. The flowering time of *E. pulchella* was two months later than usual for this normally low-altitude species. It consequently overlapped the flowering period of both sub-alpine species *E. coccifera* and *E. delegatensis* and had its peak flowering period intermediate between the two. The movements of pollinators across the species boundaries indicated the potential for hybridisation between *E. pulchella* and the other two species.

Adult morphology suggested that the Snug Plains *E. pulchella* tended towards *E. coccifera* compared to typical, low-altitude *E. pulchella* and progeny tests reinforced this view. In addition, two out of twelve *E. pulchella* adults sampled appeared intermediate between this species and *E. coccifera* and produced progeny overlapping those from *E. coccifera*. These results suggest that introgression of *E. coccifera* genes may be occurring into *E. pulchella* at Snug Plains although adaptive convergence cannot be excluded. Quite a different picture is seen for the results of hybridisation between *E. pulchella* and *E. delegatensis*. Six putative F_1 hybrids between *E. pulchella* and *E. delegatensis* occurred in progeny from two *E. pulchella* mothers. However, this appears to have had little genetic impact on the species, since no evidence of introgression or convergence was apparent in adult populations of these species.

Key Words: gene flow, hybridisation, introgression, eucalypt species, Tasmania

INTRODUCTION

While genetic isolation appears to be maintained at the subgeneric level in the genus *Eucalyptus*, there are few absolute barriers to interbreeding between species within a subgenus although the extent of natural hybridisation varies considerably (Curtis & Morris 1975, Pryor 1976). In Tasmania hybridisation between closely related species from the informal series *Piperitae* (subgenus *Monocalyptus*, Pryor & Johnson 1971) is common (Potts & Reid 1983, 1985a) with many recognised taxa exhibiting complete intergradation (e.g. Shaw *et al.* 1984). In contrast, despite frequent geographical contact between species from the series *Piperitae* and the series *Obliquae* (also subgenus *Monocalyptus*), there are only a few records of inter-series hybrids (Pryor 1957a, Jackson 1958, Potts & Reid 1983). In the present study we compare the extent of inter-series and intra-series hybridisation and gene flow between two *Piperitae* species (*E. pulchella* Desf. and *E. coccifera* Hook. f.) and one *Obliquae* species (*E. delegatensis* R.T. Baker) at Snug Plains in southeastern Tasmania by examining the flowering phenology and adult and seedling morphology.

Snug Plains is one of the few areas where these three species can be found in parapatry and is unique since an extensive plateau occurs at an intermediate altitude (approx. 600 m) near the upper and lower altitudinal limits respectively of the lowland (e.g. *E. pulchella*) and sub-alpine (e.g. *E. coccifera* and *E. delegatensis*) eucalypt floras. A complex mosaic of eucalypt species occurs on the plateau in response to microhabitat variations arising from the interaction of ecological factors such as frost, drought and water logging (Davidson & Reid 1985, 1987, Davidson 1986).

MATERIALS AND METHODS

The study site was a shallow rocky ridge on the eastern side of Snug Plains at an altitude of 600 m (see Davidson & Reid 1985 for details) where a small population of *E. pulchella* (200-500 mature trees) approximately 50 m wide followed the ridge crest for 0.5 km flanked by populations of *E. coccifera* to the west and *E. delegatensis* to the east. At this site herbarium samples of adult foliage (fig. 1) and fruit were collected from six trees of *E. delegatensis* and *E. coccifera* and two samples of six trees of *E. pulchella*. The first *E. pulchella*

FIG.1 — Typical adult leaves for lowland E. pulchella *(1), Snug Plains* E. pulchella *from the ridge top (2) and a shallow depression (associated with* E. coccifera*) (3), Snug Plains* E. coccifera *(4), and Snug Plains* E. delegatensis *(5).*

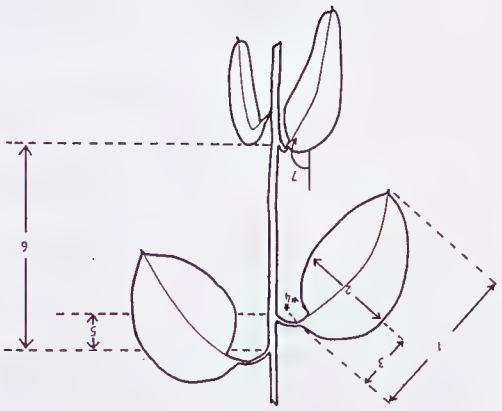

FIG.2 — Seven of the morphological characters measured from seedling leaves: 1 = lamina length, 2 = lamina width, 3 = length to widest point of the lamina, 4 = basal asymmetry of the leaf, 5 = intranode length, 6 = internode length, and 7 = leaf rotation (from the vertical).

population came from a ridge top site where shallow soil occurred over dolerite bedrock, while the second came from a slight depression in the ridge crest with deeper soil in which adults of both *E. pulchella* and *E. coccifera* occurred (near stand D, fig. 2 in Davidson & Reid 1985). A separate collection of herbarium specimens and fruit was also made for six trees from a lowland population of *E. pulchella* at a site 5 km east of the study area, at an altitude of approximately 100 m. Six representative leaves and 20 capsules were selected from the material collected from each tree. A limited set of morphological characters was measured for the adult leaves and air-dry weights were obtained for the capsules. The leaf characters measured were a subset of those used by Potts & Reid (1983) and were previously shown to be sufficient to discriminate between *Monocalyptus* species (Potts & Reid 1983, 1985a). They included petiole length, leaf lamina length, leaf lamina width, length to widest point of the leaf, and basal asymmetry of the leaf (fig. 2). Statistical analysis of the adult leaf and fruit data set included analysis of variance and canonical variates analysis. Canonical variates analysis (Seal 1966) has been widely used in the study of hybridisation in *Eucalyptus* (e.g. Hopper *et al.* 1978, Potts & Reid 1983).

Progeny trials were conducted for the five populations sampled in the field [lowland *E. pulchella*, Snug Plains *E. pulchella* (two populations), Snug Plains *E. coccifera*, and Snug Plains *E. delegatensis*]. The seed, which was collected concurrently with the herbarium samples from six adult trees, was stratified for four weeks at 4° C in a cold room, then germinated on moist vermiculite and pricked out, at the cotyledonary stage, into plywood veneer tubes filled with potting soil. Ten replicate seedlings were planted for each tree (a total of 300 seedlings). The seedlings were arranged in a randomised block design, with an edge row in a glasshouse. The seedlings were watered three times weekly and nutrient was supplied via slow release fertilisers (Osmocote, blood and bone) present in the potting mix.

After four months growth a single leaf was removed from nodes 5, 7 and 10 of each seedling and a set of morphological characters measured for each leaf. The set of measurements made for the seedling leaves were the same as those measured for adult leaves apart from addition of measures of leaf glaucousness (scored on a 1 to 5 scale), lamina thickness and rotation of the leaf to the vertical [scored on a 1 (horizontal) to 4 (vertical) scale, fig. 2]. Where seedling leaves were sessile (e.g. *E. coccifera*) basal leaf width at the point of junction with the stem was measured. This measure was

combined in one variable with petiole length by recording it as a negative distance, mutually exclusive to a positive petiole length (see Potts & Reid 1985a). Internode length and intranode length were also measured at nodes 5, 7 and 10. Internode length was measured between the node at which the leaf characters were measured and the immediately preceding node. Analysis of variance and canonical variates analysis was performed on the above set of seedling morphological characters. The data for node 10 only are presented since essentially similar results were obtained from the analysis of data from each node.

The field populations of *E. pulchella* (ridge top population), *E. coccifera* and *E. delegatensis* at Snug Plains and the lowland population of *E. pulchella* were also assessed for time and intensity of flowering. The same random sample of thirty trees were visually assessed on each visit to each population. The sites were visited fortnightly between October 1981 and April 1982 and the intensity of flowering was scored on a 1 to 10 scale (0 = no open flowers) for each tree and a population mean determined.

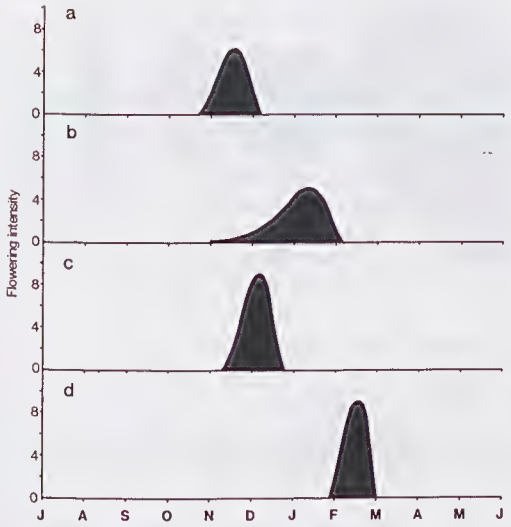

FIG.3 — Flowering time (month) versus intensity (on a 0 to 10 scale) during 1981-82 for: (a) lowland E. pulchella, *(b) the ridge top population of* E. pulchella *at Snug Plains, (c) Snug Plains* E. coccifera, *and (d) Snug Plains* E. delegatensis.

RESULTS

Flowering Time

The flowering time of the three *Monocalyptus* species present on Snug Plains (600 m), *E. pulchella*, *E. coccifera* and *E. delegatensis*, overlapped (fig. 3). The peak flowering time for typical Snug Plains *E. pulchella* from a ridge site was midway between the peaks for *E. coccifera* and *E. delegatensis* and showed a skewed distribution, starting at a low intensity before, and continuing throughout, the flowering period of *E. coccifera*. This indicated the potential for hybridisation exists between these three largely parapatric eucalypt species, although the probability of *E. pulchella* hybridising with *E. coccifera* or *E. delegatensis* would be much greater than hybridisation between *E. coccifera* and *E. delegatensis*. The peak flowering time for the Snug Plains *E. pulchella* was two months later than for *E. pulchella* from a nearby low altitude site (100 m) and the Snug Plains *E. coccifera* was more than a month earlier than normal for this species (Potts & Reid 1983). Observations of the movements of New Holland honeyeaters (*Phylidonyris novaehollandiae*), yellow wattle birds (*Anthochaera paradoxa*) and a variety of pollinating insects which fed from flowers in the crown of each of the species at Snug Plains indicated that these pollinators move indiscriminantly across species boundaries during occasions when the flowering periods of the eucalypt species overlapped.

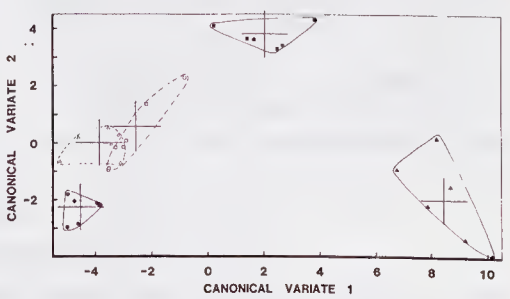

FIG.4 — Canonical variate 1 versus canonical variate 2 derived from an analysis of six morphometric characters measured on adult foliar and capsule material collected in the field for: lowland E. pulchella *(●), Snug Plains* E. pulchella *from the ridge top (△), and shallow depression (□), Snug Plains* E. coccifera *(■), and Snug Plains* E. delegatensis *(▲). Means are shown for each population.*

TABLE 1

Adult Foliar and Capsule Parameters

Mean (± S.E.) leaf lamina length (LL), leaf lamina width (LW), length to the widest point of the leaf (LWP), petiole length (PL), basal asymmetry of the leaf (Basym), and capsule weight (Cap.wt.), measured for adult foliar and capsule material collection from lowland *E. pulchella*, Snug Plains *E. pulchella* from the ridge top and the shallow depression, *E. coccifera* and *E. delegatensis*. n = 6.

Species	LL (mm)	LW (mm)	LWP (mm)	PL (mm)	Basym (mm)	Cap.wt (g)
E. pulchella (low)	105.4±2.5	6.36±0.09	54.6±1.6	6.59±0.18	0.156±0.005	0.053±0.002
E. pulchella (ridge top)	79.4±1.3	7.68±0.13	42.4±0.5	7.54±0.20	0.144±0.010	0.135±0.006
E. pulchella (depression)	79.6±0.7	9.15±0.44	39.7±0.4	10.17±0.54	0.213±0.009	0.170±0.014
E. coccifera	84.1±1.5	19.44±0.96	35.3±0.9	16.21±0.62	0.383±0.097	0.346±0.004
E. delegatensis	111.9±2.0	26.27±0.27	29.8±0.8	21.59±0.61	6.839±0.379	0.266±0.009

Adult Morphology

The five populations differed significantly ($P < 0.001$) for each of the six adult characters scored (table 1). The two populations of *E. pulchella* from Snug Plains were intermediate between the low altitude *E. pulchella* and the *E. coccifera* populations for all characters except lamina length and basal asymmetry of the leaf.

Canonical variates analysis of the adult characters clearly separated the *E. coccifera*, *E. delegatensis* and low altitude *E. pulchella* populations (fig. 4). Canonical variate 1 (CV1) contained 81% of the variation and mainly separated *E. delegatensis* from the two *Piperitae* species and was dominated by a comparison between lamina length and length to the widest point of the leaf. Canonical variate 2 (CV2, 17% of variation) mainly discriminated between *E. coccifera* and *E. pulchella* populations based primarily on a comparison of capsule weight and lamina length. The high altitude *E. pulchella* populations from Snug Plains were distinct from the low altitude *E. pulchella* population and tended in the direction of *E. coccifera*.

Seedling Morphology

Analysis of variance indicated significant differences ($P < 0.001$) between the five populations for all ten characters scored (e.g. table 2). Canonical variates analysis using the ten seedling characters clearly separated the progeny from the *E. coccifera*, *E. delegatensis* and low altitude *E. pulchella* populations (fig. 5). Canonical variate 1 contained 76% of the variation and discriminated *E. delegatensis* from the other populations based on petiole length and lamina length while canonical variate 2 (22% of variation) discriminated *E. coccifera* from the other populations and contrasted lamina width with lamina length and petiole length. The progeny from the two Snug Plains populations of *E. pulchella* were intermediate (figs 5 and 6) and

TABLE 2

Juvenile Foliar Parameters

Mean (± S.E.) for log (lamina length/lamina width) (log LL/LW), petiole measure (PM) and basal asymmetry (Basym) for juvenile leaves of progeny from lowland *E. pulchella* (n = 52), Snug Plains *E. pulchella* from the ridge top (n = 57) and the shallow depression (n = 55), *E. coccifera* (n = 53) and *E. delegatensis* (n = 51).

Species	log LL/LW	PM (mm)	Basym (mm)
E. pulchella (low)	0.99±0.019	-2.8±0.34	0.00±0.000
E. pulchella (ridge top)	0.73±0.022	-5.1±0.63	0.10±0.046
E. pulchella (depression)	0.63±0.027	-11.7±0.87	0.03±0.021
E. coccifera	0.12±0.010	-28.1±0.53	0.00±0.000
E. delegatensis	0.22±0.008	8.5±0.40	4.02±0.245

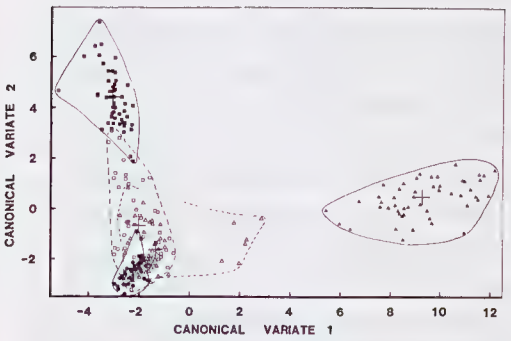

FIG.5 — Canonical variate 1 versus canonical variate 2 derived from an analysis of ten morphometric characters measured at the tenth node from glasshouse grown progeny of: lowland E. pulchella *(●), Snug Plains* E. pulchella *from the ridge top (△) and a shallow depression (associated with* E. coccifera*) (□), Snug Plains* E. coccifera *(■), and Snug Plains* E. delegatensis *(▲). Means are shown for each population.*

FIG.6 — Typical seedling leaves from progeny of lowland E. pulchella *(1), Snug Plains* E. pulchella *from the ridge top (2) and a shallow depression (associated with* E. coccifera*) (3), Snug Plains* E. coccifera *(4), and Snug Plains* E. delegatensis *(5).*

showed greater variability than the low altitude, allopatric *E. pulchella* population. However, in all but the progeny from one tree this increased variability seemed to be a result of interdependence of the variance and the mean on CV2 (fig. 7).

The two Snug Plains *E. pulchella* populations were significantly different (table 2). Both produced individuals overlapping the low altitude *E. pulchella* population and also individuals tending towards

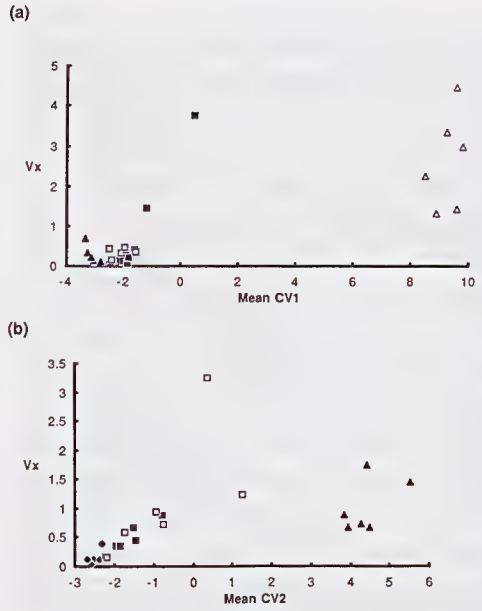

FIG.7 — The variance of CV1 (a) and CV2 (b) scores (see fig. 5) plotted against the mean value for open pollinated progenies of lowland E. pulchella *(◆), samples of* E. pulchella *from the ridge top (■) and shallow depression (□) on Snug Plains,* E. coccifera *(▲) and* E. delegatensis *(△) from Snug Plains.*

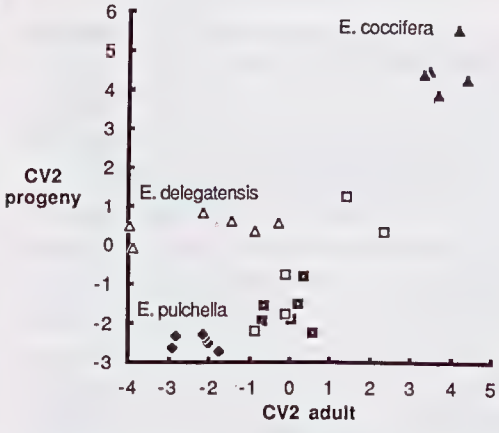

FIG.8 — The progeny mean score on CV2 (fig. 5) plotted against the score of the maternal phenotype on CV2 from the analysis of adult morphology (fig. 4). Population symbols follow figure 7.

the *E. coccifera* population (fig. 5). However, in the ridge top population two trees phenotypically identical in adult morphology to normal Snug Plains *E. pulchella*, produced six individuals (11%) clearly separate from all other *E. pulchella* progeny and intermediate between typical progenies of *E. pulchella* and *E. delegatensis* as opposed to *E. coccifera* progeny (figs 5 and 6). Five of these intermediate types arose in progeny from a single *E. pulchella* tree and there can be little doubt these outliers are a result of F_1 hybridisation between *E. pulchella* and *E. delegatensis*. The presence of these outliers had a marked effect on the variability of these two *E. pulchella* progenies which were clearly more variable for canonical variate 1 than were the progeny from the other four trees from the ridge top site (fig. 7). The Snug Plains *E. pulchella* population sampled from the shallow depression produced individuals showing continuous variation up to and overlapping the distribution of *E. coccifera* progeny (fig. 5). There was a high percentage (*c.* 22%) of individuals in this population which, in this direction, lay beyond the range of *E. pulchella* progeny from the other Snug Plains population. The progeny overlapping the range of *E. coccifera* were mainly descended from the two parents in this population which were intermediate in adult morphology between *E. pulchella* and *E. coccifera* (fig. 8). However, the variability in open pollinated progeny from only one of these intermediates was greater than in other parental progenies (fig. 7b).

DISCUSSION

The ecological preferences of *E. pulchella*, *E. coccifera* and *E. delegatensis* tend to result in spatial separation of these species. Direct genetic interaction is frequently restricted to boundary zones (e.g. *E. coccifera* and *E. delegatensis*) and only rarely do stands of *E. pulchella* occur with the two sub-alpine species (e.g. *E. pulchella* and *E. coccifera* on Middle Peak, Shaw *et al.* 1984). Prezygotic reproductive isolation is further accentuated by differences in flowering time. The flowering times are usually distinct with *E. pulchella* flowering before either of the other two species. In its "normal" ecological position *E. pulchella* has almost completed flowering before *E. coccifera* commences, while *E. delegatensis* flowers after *E. coccifera* (Potts & Reid 1983). However, at Snug Plains all three species are parapatric and intermingle in boundary regions. *E. pulchella* flowers between the other two species and overlaps both. Together with the observed indiscriminate movement of pollinators these conditions clearly suggest the potential for pollen transfer between *E. pulchella* and the other two species at this site. The reversed flowering of *E. coccifera* and *E. pulchella* may be partly a consequence of populations of both species occurring at the upper and lower altitudinal extremes of their species range as flowering time has been reported to be delayed with increasing altitude in several eucalypt species (e.g. Barber & Jackson 1957, Griffin 1980, Shaw *et al.* 1984).

Six progeny from two of the *E. pulchella* mothers from the ridge top population at Snug Plains (fig. 7a) were intermediate in phenotype between the *E. pulchella* and *E. delegatensis* seedlings (fig. 5) and are most likely F_1 hybrids between *E. pulchella* and *E. delegatensis*. They were intermediate not only in the characters scored but in all other observable characteristics. No such individuals were found in progeny from the *E. delegatensis* mothers sampled nor progeny from the other population of *E. pulchella* sampled on Snug Plains. This asymmetric hybridisation between *E. pulchella* and *E. delegatensis* could be due to several factors including the effect of flower size (Tibbits 1986) and the earlier flowering of the *E. pulchella*. The protandrous nature of eucalypt flowers (Pryor 1976, Griffin & Hand 1979) would favour pollen of the later flowering species pollinating the earlier flowering species. A similar asymmetry has been noted between *E. risdonii* and *E. amygdalina* (Potts & Reid 1985a, Potts 1986). The adult population samples from the study site at Snug Plains (fig. 4) showed no tendency for individuals intermediate between *E. pulchella* and *E. delegatensis* but in a widespread examination of the natural stands in the region a single localised hybrid swarm was discovered (saplings 4 to 6 m tall). This suggests that although hybridisation may occur between these species the F_1 individuals only occasionally survive to maturity and consequently there is probably little gene exchange between these species at Snug Plains.

A very different picture is found when examining the interaction between the two *Piperitae* species. In both adult (fig. 4) and progeny (fig. 5) morphology the Snug Plains *E. pulchella* trees tend towards *E. coccifera* in phenotype relative to the trees from the low altitude *E. pulchella* population. This occurs for reproductive as well as vegetative characters. Further, at least two adults from the Snug Plains *E. pulchella* population in the slight depression (associated with *E. coccifera*) are intermediate between the rest of this population and *E. coccifera* (fig. 8) and may well represent hybrids between these two species. Some of the offspring

from these two trees overlap the distribution of the *E. coccifera* progeny (fig. 5). The lack of increased variability amongst progeny from one of these two trees suggests advanced generation hybridisation (fig. 7b). Furthermore, with populations of *E. pulchella* at Snug Plains significantly different from lowland *E. pulchella* and tending in the direction of *E. coccifera*, there is the possibility that this divergence is a result of introgression of *E. coccifera* genes into the *E. pulchella* population and subsequent genetic stabilisation. Such introgression could be of adaptive significance since the reduced leaf lengths found in the Snug Plains *E. pulchella* populations may be less prone to wind and ice damage in the sub-alpine environment. *E. coccifera* genes may also confer increased frost resistance on the *E. pulchella* population (see Davidson & Reid 1985). However, similar convergence of *E. pulchella* toward the *E. coccifera* phenotype could result from adaptive differentiation within *E. pulchella* since the direction of divergence (in several characters) is similar to that noted to occur with altitude in other *Eucalyptus* species. For example, in many species leaf length is reduced (Pryor 1957b, Barber & Jackson 1957, Phillips & Reid 1980, Shaw *et al.* 1984, Potts & Reid 1985b) and capsule size is increased (e.g. Phillips & Reid 1980, Shaw *et al.* 1984) with increasing altitude. In either case, the presence of phenotypes similar to the low altitude *E. pulchella* in the seedling cohort (fig. 5), but the absence of overlap in the adult populations may reflect strong selection against low altitude *E. pulchella* types at Snug Plains although this remains to be verified.

The plateau at Snug Plains is environmentally heterogeneous, with slight topographic changes resulting in various areas exposed to severe frosts and waterlogging while other areas are subject to drought (Davidson & Reid 1985, 1987; Davidson 1986). This results in a unique and complex mosaic of "typically" lowland and sub-alpine eucalypt species. Furthermore, with the intermediate altitude of the plateau it is conceivable that slight climatic changes may have a pronounced effect on its suitability as a habitat for lowland and sub-alpine eucalypt species. The introgression of *E. coccifera* genes into the *E. pulchella* gene pool may have allowed the lowland species, *E. pulchella*, to maintain a foothold in this largely sub-alpine region and avoid extinction. Adaptive introgressive hybridisation may genetically buffer a species against environment change, increasing evolutionary flexibility and allowing population stability in an unstable environment. Nevertheless, the genetic and evolutionary consequences of hybridisation may vary markedly and while the present study demonstrates active F_1 hybridisation between *E. pulchella* and *E. delegatensis*, this seems to have had little genetic impact.

ACKNOWLEDGEMENTS

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(accepted 23 March 1987)

TASMANIAN BATS: IDENTIFICATION, DISTRIBUTION AND NATURAL HISTORY

by Robert J. Taylor, Mark G. O'Neill and Terry Reardon

(with two tables and five text-figures)

TAYLOR, R.J., O'NEILL, M.G. & REARDON, T., 1987 (30:vi): Tasmanian bats: identification, distribution and natural history. *Pap. Proc. R. Soc. Tasm.*, 121: 109-119. ISSN 0080-4703. Department of Zoology, University of Tasmania, Sandy Bay, Tasmania 7005 (R.J.T. & M.G.O'N.); and Evolutionary Biology Unit, South Australian Museum, Blacks Road, Gilles Plains, S.A. 5086 (T.R.).

A review of the natural history of bats in Tasmania is presented along with data collected in recent surveys. Recent taxonomic changes affecting the Tasmanian bat species are discussed and a key is provided to allow the identification of Tasmanian bats. The appearance of each species is described and body measurements given. Tasmanian populations do not show a uniform trend of increased size compared with southeast Australian populations. Distribution records are presented along with data on habitat preferences and abundance. The diet, activity patterns, roosting requirements, reproductive cycles and conservation status of the species are also discussed.
Key Words: Tasmania, bats, key, diet, reproduction, conservation status, distribution.

INTRODUCTION

In the past the study of bats has been hindered by the difficulty of catching and observing them. The recent development of harp traps (Tidemann & Woodside 1978) has lead to a dramatic increase in the work being conducted on this group of mammals (e.g. Inwards & Phillips 1982, Tidemann 1982, Churchill *et al.* 1984). In 1983 the authors began an ecological investigation of Tasmanian bats using these new catching techniques. Some data are available on Tasmanian bats (Green 1965, 1966, 1973, Green & Rainbird 1984); however our studies pointed to the need to synthesize and update this information. In this paper we provide a key to enable the eight species present in Tasmania to be identified and we review the natural history of these bats, including some new data collected during our studies.

COMPOSITION AND SYSTEMATICS

The bat fauna of Tasmania is composed of eight species representing four genera, all belonging to the microchiropteran family Vespertilionidae. A further species the grey-headed flying fox *Pteropus poliocephalus* occasionally reaches the Bass Strait islands (Hall & Richards 1979) but has not yet been recorded on Tasmania proper. The following summary covers the taxonomic reviews relevant to Tasmanian species and accounts for the nomenclature used in this paper.

Eptesicus vulturnus Thomas, 1914

Originally described by Thomas as *Eptesicus pumilus vulturnus*, type region Tasmania. Adams *et al.* (in press) distinguish two species within *E. vulturnus*. One species is an arid inland species and the other, with which Tasmanian specimens are conspecific, has a southern coastal distribution from Adelaide to near Sydney.

Eptesicus regulus Thomas, 1906

Tasmanian and southeastern mainland specimens are genetically indistinguishable by allozyme electrophoresis (Adams *et al.* in press).

Eptesicus sagittula
McKean, Richards and Price, 1978

Adams *et al.* (in press) distinguish two species within *E. sagittula* using allozyme electrophoresis. Tasmanian specimens are conspecific with the southern species, which ranges coastally from Adelaide to Brisbane. The northern species is distributed coastally northwards from Newcastle, N.S.W.

Chalinolobus morio Gray, 1841

Originally described as *Scotophilus morio*. Type location as Tasmania (*fide* Iredale & Troughton 1934). Indistinguishable from mainland specimens on allozyme electrophoresis (Adams *et al.* in press).

Chalinolobus gouldii Gray, 1841

Originally described as *Scotophilus gouldii*, type locality Launceston, Tasmania. Evidence from morphology (Tidemann 1985) supports the recognition of a single species throughout Australia.

Nyctophilus geoffroyi pacificus Gray, 1831

Although Tasmanian populations of *Nyctophilus geoffroyi* tend to be darker and larger than mainland populations most authors agree with Thomas (1915) in recognizing a single subspecies in southeastern Australia.

Nyctophilus timoriensis sherrini Thomas, 1915

There has been some confusion over the specific identity of the larger species of *Nyctophilus* in Tasmania. It was originally described from Tasmania as *N. sherrini*, but until 1979 most authors agreed that this form was a subspecies of *N. timoriensis* (Troughton 1941, Tate 1942, Ride 1970). Hall & Richards (1979) noted that *N. gouldi* had been recently collected from Tasmania with the implication that *N. t. sherrini* was in fact *N. gouldi*. Subsequent to 1984 authors continued to recognise *N. gouldi* as the correct identity for the large long-eared bats in Tasmania (Green 1983, Richards 1983a, O'Neill 1984, but see Hall 1981). However it appears that Hall & Richards (1979) based their identification on a specimen of *N. geoffroyi* (Parnaby in press), these being larger than mainland animals.

Koopman (1984), upon examining the type of *N. sherrini*, concluded it was a subspecies of *N. timoriensis*, explaining that confusion with *N. gouldi* probably arose because the type was "somewhat immature" giving rise to the smaller measurements. We have followed Koopman (1984) in recognising *N. timoriensis* as the correct name for the long-eared bat in Tasmania.

Nictophilus timoriensis has a patchy distribution across southern Australia including northern Victoria (Richards 1983b) and is the only species where subspecific level differentiation can be recognized between Tasmania and the mainland.

Falsistrellus tasmaniensis Gould, 1858

Tasmania is the type region of this bat. Until recently known as *Pipistrellus tasmaniensis*. In a recent taxonomic review of Australian *Pipistrellus*, Kitchener *et al.* (1986) made generic distinction between the large southern species and the small northern species. In southern Australia they identified two species, *Falsistrellus mckenziei* in the west and *F. tasmaniensis* in the east including Tasmania.

APPEARANCE

Pelage colour can be an important aid in distinguishing species. This is especially so with the genus *Eptesicus*. In *E. vulturnus*, the smallest Tasmanian bat, the fur on the dorsal surface is generally mid to dark grey. Ventrally the fur is usually dark grey with a distinct light grey or off-white tip. Pelage colour in this species is, however, variable and some individuals may have a browner fur and lack the white tips on the ventral hair. From our experience it appears that populations in southern Tasmania may contain a higher percentage of individuals with grey predominating in their pelage than in northern Tasmania. The tragus (an upright flap of skin within the ear) is usually translucent white. This character is, however, also variable with some individuals having a tragus merging in colour with the rest of the ear. The skin over the dorsal surface of the forearm is paler than that of the wing membrane.

Eptesicus regulus has reddish brown dorsal fur with lighter brown fur on the ventral surface. Older animals sometimes lack the reddish tinge to their fur. *E. sagittula* varies from dark grey brown in smaller individuals to very dark brown or almost black in larger individuals. Neither *E. regulus* nor *E. sagittula* has a white tragus and skin colour on the forearm does not contrast with that of the wing membrane as it does in *E. vulturnus*.

The two species of *Chalinolobus* can be differentiated from the other genera by fleshy lobes present at the base of the ear and the corner of the mouth and by the elevated appearance of the forehead. *C. morio* is smaller than *C. gouldii* and the fur is a uniform chocolate brown all over. *C. gouldii* is much darker in appearance than *C. morio* having dark brown fur on the back and black fur around the head and shoulders with a slightly lighter brown colouration ventrally.

The two *Nyctophilus* species are easily recognized by their large ears. The ears are joined over the head and are ribbed posteriorly enabling them to be folded. *N. geoffroyi* is smaller than *N. timoriensis* and has a well developed Y-shaped noseleaf. Its fur is light grey-brown dorsally and slightly paler ventrally. In *N. timoriensis* the noseleaf is poorly developed. Its fur is dark brown above and lighter brown below. The colouration of its dorsal fur is similar to that of *N. geoffroyi* but the ventral fur is slightly darker tan.

Falsistrellus tasmaniensis, the largest Tasmanian bat, has long pointed ears with a characteristic notch on the outer margin near the tip. It has reddish brown fur on the dorsal surface and lighter brown fur on the belly.

TABLE 1

Forearm lengths (mm) for Tasmanian bat species and for the same species in southeastern Australia.

Significance of the difference between sexes and areas was examined using t-tests.

		Tasmania				Southeastern Australia			
Species	**Sex**	**Numbers of individuals**	**Mean ±S.D.**	**Range**	**Comparison of sexes**	**Numbers of individuals**	**Mean±S.D.**	**Comparison of sexes**	**Comparison of areas**
Eptesicus vulturnus	M	52	29.1±0.7	27.2-30.7*	$p<0.01$	29	28.2±0.8	$p<0.001$	$p<0.001$
	F	18	29.7±0.6	28.0-31.7*		40	29.2±0.8		$p<0.5$
Eptesicus regulus	M	79	32.4±0.9	31.0-34.9	$p<0.001$	33	32.8±0.7	$p<0.001$	$p<0.05$
	F	122	33.2±0.8	31.5-35.6		30	34.0±0.7		$p<0.001$
Eptesicus sagittula	M	45	34.9±0.9	32.0-37.0*	N.S.	29	35.6±0.7	$p<0.001$	$p<0.01$
	F	22	34.7±0.9	33.1-36.1*		30	36.3±0.8		$p<0.001$
Chalinolobus morio	M	91	40.2±0.9	36.2–42.8	$p<0.001$	30	38.3±1.0	$p<0.01$	$p<0.001$
	F	70	41.2±1.0	38.6-43.0		30	39.6±0.8		$p<0.001$
Chalinolobus gouldii	M	11	45.9±1.3	44.0-48.7	N.S.	33	47.1±1.3	N.S.	$p<0.01$
	F	14	46.2±0.9	45.0-47.5		41	47.6±1.5		$p<0.01$
Nyctophilus geoffroyi	M	27	39.2±1.3	36.5-42.6	$p<0.001$	30	37.1±1.0	$p<0.001$	$p<0.001$
	F	35	40.9±0.7	39.5-42.4		30	38.5±0.8		$p<0.001$
Nyctophilus timoriensis	M	13	45.6±1.0	43.9-48.0	N.S.				
	F	10	46.5±1.0	44.8-48.0					
Falsistrellus tasmaniensis	M	39	49.4±1.0	46.0-51.2	N.S.	31	52.1±1.2	N.S.	$p<0.001$
	F	16	49.9±1.3	47.4-52.2		10	52.1±1.1		$p<0.001$

* Maximum or minimum values from Green & Rainbird (1984) included.

IDENTIFICATION

The descriptions given in the previous section have been used in conjunction with data on forearm length (table 1) to provide a dichotomous key which will allow greater ease of identification in the field. Forearm measurements should be taken with vernier calipers as shown in figure 1.

KEY TO BATS OF TASMANIA

1 Ears long and broad, joined over the head and can be folded ... *Nyctophilus* (fig. 2C) 2
Ears not joined over head and not capable of being folded, ears if long then not broad 3

2(1) Forearm length <43 mm; nose leaf well-developed (elevated lobe of skin with distinct Y-shaped groove in centre, fig. 3A) ... *N. geoffroyi*
Forearm length >43 mm; nose leaf not well-developed (ridge of skin with a slight central depression, see fig. 3B) ... *N. timoriensis*

3(1) Fleshy lobes present at base of the ear and at the corner of the mouth ... *Chalinolobus* (fig. 2A) 4
No fleshy lobes present at the base of the ear or at the corner of the mouth 5

4(3) Forearm length <43.5 mm, fur on dorsal surface is uniformly chocolate brown ... *C. morio*
Forearm length >43.5 mm, fur on dorsal surface is dark brown tending to black on head and shoulders ... *C. gouldii*

5(3) Forearm length <38 mm ... *Eptesicus* (fig. 2B) 6
Forearm length >38 mm ... *Falsistrellus tasmaniensis*, fig. 2D)

6(5) Colour of skin on upper forearm distinctly lighter than on wing membrane, forearm length for males is <31 mm and for females is ≤31.7 mm ... *E. vulturnus*
Colour of skin on upper forearm as for wing membrane, forearm length for males is ≥31 mm and for females ≥31.5 mm 7

7(6) Fur on dorsal surface usually reddish-brown, forearm length of males 31-35 mm, forearm length of females 31.5-35.6 mm ... *E. regulus*
Fur on dorsal surface is usually dark brown or almost black forearm length of males ≥32 mm, forearm length for females is ≥33 mm ... *E. sagittula*

It should be noted that the three species of *Eptesicus* cannot always be positively identified from external features alone. Pelage colour varies within species and can overlap in the different species. For example, some *E. regulus* may lack the reddish tinge to their fur and thus look much like *E. sagittula*. Forearm length can usually be used to separate *E. vulturnus* from the other two species as there is only a small overlap (0.2 mm) between females of *E. vulturnus* and *E. regulus*. *E. regulus* and *E. sagittula* on the other hand overlap extensively in forearm length. Males of each species can be positively identified by their baculum (a bone in the penis) (fig. 4). Females can be positively identified by a combination of forearm length and skull shape. The braincase of *E. regulus* in side profile has a more flattened appearance than in *E. vulturnus* and *E. sagittula* (fig. 1 in Green & Rainbird 1984). Thus *E. regulus* can be separated from *E. vulturnus* and *E. sagittula* on skull profile and *E. vulturnus* can be separated from *E. sagittula* on forearm length. With experience the profile of the skull can be judged from live specimens by feeling it through the skin and this character can then be used to identify individuals in the field.

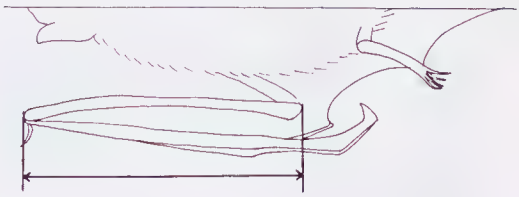

FIG.1 — Diagram showing the method for measuring forearm length.

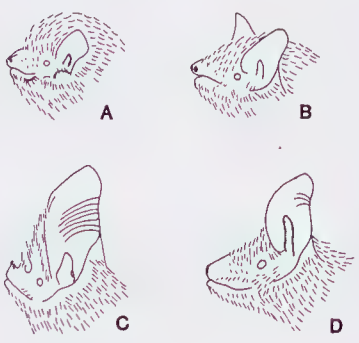

FIG.2 — Profiles showing the facial features of the four genera of Tasmanian bats: A — Chalinolobus, *B* — Eptesicus, *C* — Nyctophilus, *D* — Falsistrellus.

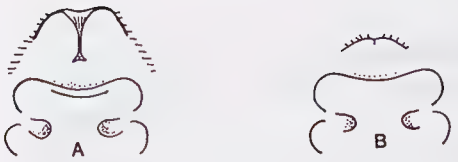

FIG.3 — Nose-leaves of the two species of Nyctophilus *in Tasmania. A* — N. geoffroyi, *B* —N. timoriensis.

BODY MEASUREMENTS

Forearm lengths and weights of adults are presented in tables 1 and 2. These data were mainly obtained during spring and summer. Weight is influenced by condition and, in females, by reproductive status. Thus lower weights than that given will probably be recorded during winter. Many pregnant females were included in the sample making any comparisons between the sexes difficult. Forearm length gives a better indication of relative size and hence was used to compare the sizes of males and females of each species. Females were significantly larger than males in *E. vulturnus*, *E. regulus*, *C. morio* and *N. geoffroyi*. The mean forearm length for *N. timoriensis* females was larger than that for males but not significantly so ($p = 0.06$). It is believed that a large data sample for this species would show females to be significantly larger than males. Data on sexual dimorphism were available for seven of the species from south-eastern Australian populations. These data were collected by W. Phillips and S. Inwards in the Brindabella Ranges of the A.C.T. and by C. Tidemann (for most of the *E. vulturnus* and half of the *C. gouldii*) from the south coast of N.S.W. All of these species except for *E. sagittula* showed the same trend as that found in Tasmania, i.e. females were significantly larger than males in southeastern Australia. The reason for this difference is not known; we believe the data from southeastern Australia probably reflect the true picture for this species. If this is the case then only the two larger species which are the faster flyers (*N. timoriensis* is a slower flyer according to O'Neill & Taylor 1986) are not sexually dimorphic. For mammals in general, as body size is reduced, the weight of young produced as a proportion of maternal weight increases (Leitch *et al.* 1959). Myers (1978) has concluded that sexual dimorphism in vespertilionid bats is correlated with the difficulty of flying with and nourishing a large foetus.

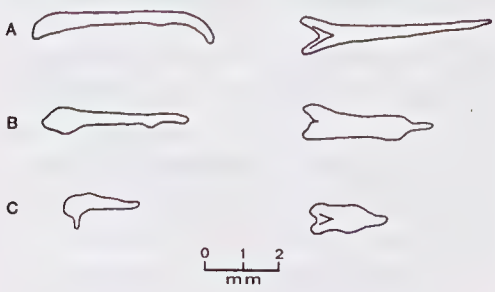

FIG.4 — Side profile (left) and dorsal view of the bacula from the three species of Eptesicus *in Tasmania: A* — E. vulturnus, *B* — E. regulus, *C* —E. sagittula *(after McKean* et al. *1978).*

It has been shown for *N. geoffroyi* (Ryan 1963) and for *C. gouldii* (Tidemann 1986) that forearm length increases with latitude. Data from southeastern Australian populations were used to test whether the other species exhibited this increase in size in Tasmania compared with more northern populations. It was found that all species exhibited significant differences in forearm length compared with the southeastern Australian populations (table 1); however some species were smaller in Tasmania. The pattern which emerges appears to be that of a reduction in the size range of species within a genus. Thus, for *Eptesicus* and *Chalinolobus*, the smallest species is significantly larger and the largest species is significantly smaller than the mainland populations. The largest Tasmanian bat *Falsistrellus tasmaniensis* is smaller than the mainland population. The result for *C. gouldii* is contrary to the trend of increasing size with increasing latitude (Tidemann 1986). Our values for *C. gouldii* are similar to those given by Tidemann (1986) for Tasmania but the forearm lengths for the mainland populations are greater than would be predicted from Tidemann's results.

DISTRIBUTION AND HABITAT PREFERENCES

Figure 5 shows the locations from which each of the eight species have been collected in Tasmania. Our records were obtained during five to ten nights trapping with harp traps at eight sites detailed in O'Neill (1984) and Taylor & O'Neill (1986) and at a further nine sites using both harp traps and mist nets for usually only one night. Data from trapping by others (see Acknowledgements) at a further seven sites were also available. All other records were obtained from museums and the Tasmanian

TABLE 2

Weights (g) for Tasmanian bats.

Species	Sex	Number of individuals	Mean±S.D.	Range	Comparison of sexes
Eptesicus vulturnus	M	51	4.1±0.3	3.7–4.7	$p<0.001$
	F	17	4.5±0.4	3.9-5.6	
Eptesicus regulus	M	77	5.0±0.5	4.1-6.7	$p<0.001$
	F	115	5.5±0.7	3.8-7.7	
Eptesicus sagittula	M	42	6.1±0.6	4.9-7.8	N.S.
	F	20	6.0±0.9	4.8-7.6	
Chalinolobus morio	M	90	8.9±0.8	6.7-11.4	$p<0.001$
	F	69	10.0±1.4	7.3-13.7	
Chalinolobus gouldii	M	7	14.4±1.3	12.2-16.2	N.S.
	F	9	15.0±1.7	12.9-17.8	
Nyctophilus geoffroyi	M	26	8.3±0.8	6.8-9.9	$p<0.001$
	F	34	10.2±1.0	7.4-12.2	
Nyctophilus timoriensis	M	13	12.7±2.3	9.9-18.9	N.S.
	F	10	13.1±1.5	9.8-14.9	
Falsistrellus tasmaniensis	M	32	19.4±1.8	16.2-24.1	$p<0.001$
	F	10	21.3±1.4	19.2-23.5	

National Parks and Wildlife Service and were mostly for animals at roost sites or that had been found dead. There was a strong bias towards eastern Tasmania in both the trapping locations and the museum records.

There are fewer records for the three larger species (*N. timoriensis*, *C. gouldii* and *F. tasmaniensis*) than for the others. All species appear to be widely distributed. *Eptesicus vulturnus*, *C. gouldii* and *N. timoriensis* have not been recorded from southwestern Tasmania, but may be found in this region with more intensive collecting. Nevertheless, species diversity of bats is likely to be lower in southwestern and western Tasmania than in eastern Tasmania. Only *N. geoffroyi* and *E. regulus* have been recorded around "Melaleuca" in Bathurst Harbour (M. Schulz & K. Menkhorst, *pers. comm.*) and four species (*E. regulus*, *E. sagittula*, *N. geoffroyi* and *C. morio*) have been recorded from rainforest in the Upper Henty River region in western Tasmania (Taylor *et al.* 1985). By contrast, in forested sites in eastern Tasmania trapping records indicate that it is not uncommon for seven or eight species to occur sympatrically. It is possible that insect populations are not as great in the western and southwestern regions or that the higher rainfall and colder conditions limit the foraging of bats in comparison with eastern Tasmania.

All species have been found in a wide range of forest habitats. *Eptesicus vulturnus* appears to favour lowland situations. Thus at a coastal dry sclerophyll forest site (elevation 140 m) 15 of the 63 *Eptesicus* captured were *E. vulturnus* whereas at two other dry sclerophyll forest sites at a higher elevation (300 and 460 m) only two out of 87 *Eptesicus* were *E. vulturnus*. A similar situation occurs in New South Wales where on the south coast *E. vulturnus* is frequently caught (Tidemann 1982) whereas in the Brindabella Ranges near Canberra this species is uncommon above 1000 m (Phillips & Inwards *pers. comm.*). *Falsistrellus tasmaniensis* and *N. geoffroyi* seem to have adapted to human environments and can be found foraging and roosting in urban and inner-city situations (Maddock 1983, Tasmanian Museum records).

RELATIVE ABUNDANCE

Data collected from sites where at least five nights trapping had been conducted were used to examine the relative frequencies of capture of each species. Forests sampled were rainforest (1 site), blackwood (*Acacia melanoxylon*) swamps (1 site),

FIG.5 — Locations from which each of the bat species has been collected in Tasmania. Solid circles indicate our records. Open circles indicate records obtained from other sources.

wet sclerophyll (2 sites), and various dry sclerophyll types (5 sites). These were located in western (1), northwestern (1) and eastern Tasmania (7). Trapping was conducted over the late spring to early autumn period. At one of the wet sclerophyll sites and one of the dry sclerophyll sites, some trapping was carried out over a pond or stream. Normally, however, traps were placed along forestry tracks.

A total of 544 bats were trapped at these sites. The relative proportions of each of the species were: *E. vulturnus* 11%, *E. regulus* 35%, *E. sagittula* 12%, *C. morio* 20%, *C. gouldii* 2%, *N. geoffroyi* 10%, *N. tasmaniensis* 3%, *F. tasmaniensis* 7%. *Eptesicus regulus* was thus the most frequently caught bat. It was three times more abundant than its congeners *E. vulturnus* and *E. sagittula*. The three largest bats, *N. timoriensis*, *C. gouldii* and *F. tasmaniensis*, were caught the least. The proportions of each species trapped cannot be directly translated into relative abundances since trappability probably varies between species (Taylor & O'Neill 1986). The authors, however, believe it is likely that the larger species are less abundant than the others.

DIET AND FORAGING PATTERNS

All species are insectivorous. Both *N. geoffroyi* and *N. timoriensis* are known to capture non-volant insects on the ground and from the surface of vegetation (Dwyer 1965, Vestjens & Hall 1977, O'Neill & Taylor in press). However, only *N. timoriensis* appears to specialize on non-volant insects. Five of the species (*E vulturnus*, *E. regulus*, *E. sagittula*, *N. geoffroyi* and *C. morio*) feed opportunistically, their diets reflecting local and seasonal variations in insect abundance and diversity. Lepidopterans make most of the diet of these species. The two larger species, *F. tasmaniensis* and *C. gouldii*, appear to be more selective feeders with coleopterans being the most important item in their diet. The sizes of insects eaten is positively correlated with the size of the bat species (with the exception of *C. gouldii*) (O'Neill & Taylor in press).

Species differ in the aerodynamic properties of their wings. This results in differences in their manoeuvrability and flight speed. Flight ability has been found to be related to habitat use with species differing in the height at which they forage and the openness of the vegetation utilized (O'Neill & Taylor 1986). *Nyctophilus geoffroyi* and *N. timoriensis* have broad wings allowing extreme manoeuvrability and slow flight. Both species feed close to the ground and, at times, amongst the undergrowth. *Eptesicus regulus* and *E. vulturnus* are faster flyers than either of the *Nyctophilus* species and generally feed around the top of the

undergrowth. *Chalinolobus morio* and *E. sagitula* feed mostly in the middle layers of the forest between the canopy and the understorey. *Falsistrellus tasmaniensis* and *C. gouldii* have relatively long narrow wings resulting in limited manoeuvrability and fast direct flight. They generally feed in the upper layers of the forest canopy or above it.

ACTIVITY PATTERNS

All species are nocturnal. During late spring and summer there is usually a bimodal pattern of activity with foraging occurring in the first three hours after dark and the three hours prior to first light in the morning. A marked decrease in activity occurs during the middle of the night (O'Neill 1984). This pattern of activity correlates well with changes in the abundance of volant insects (O'Neill 1984). However, considerable variation in activity levels may occur according to sex, age, reproductive condition, season and climatic events (Erkhert 1982). Hibernation occurs between late autumn and early spring. In the Brindabella Ranges near Canberra where seven of the eight Tasmanian species occur sympatrically, it has been found that *C. morio* enters torpor later and emerges from hibernation earlier than the other species (Phillips & Inwards 1980). This also appears to be the case in Tasmania (Taylor & Savva unpubl. data).

ROOSTING REQUIREMENTS

All Tasmanian bats are primarily tree roosters. However individuals have been found in a remarkable variety of roost types, e.g. roof and wall cavities in buildings, rolled canvas blinds, timber stacks, the exhaust pipe of a tractor and bird nests. There is only one record of the occurrence of bats in caves in Tasmania (Savva & Taylor 1986). Few data are available on the type of roosts utilized by bats in trees. Phillips *et al.* (1985) found male *F. tasmaniensis* utilizing a stem hole on the main trunk of a live *Eucalyptus dalrympleana*. Lunney *et al.* (1985) recorded roosts of *C. morio* in exceptionally large eucalypts. Two roosts of *E. sagittula* reported to the Tasmanian National Parks and Wildlife Service were in hollows of old eucalypts (D. Rounsevell *pers. comm.*). Woinarski (1986) found two bats (probably *C. gouldii*) roosting in the hollow of a stump. Recent results from a study in Tasmania point to the importance of narrow cracks in eucalypts as roost sites for bats (Taylor & Savva unpubl. data). These can be present under bark, on the trunk or in the rotten heartwood of the bole of the tree. Older trees are more likely to have suitable roost sites. Fire appears to be important in creating roost sites.

It is possible that roosting sites change over the year as microclimate preferences vary in association with seasonal changes in metabolic rate (Dwyer 1964, Ransome 1968). All species are known to roost communally at least some of the time. Males appear to be less selective in their choice of roost site and are more often found singly than are females (Tidemann *pers. comm.*).

REPRODUCTIVE CYCLES

Observations on the reproductive cycles of Tasmanian bats have been made by Green (1965, 1966) on *E. vulturnus* and *N. geoffroyi* and by O'Neill (1984) on *E. regulus*, *E. sagittula* and *C. morio*. Studies have also been conducted on several of the species on the mainland, i.e. *F. tasmaniensis* (Phillips *et al.* 1985), E. *regulus* (Kitchener & Halse 1978), *C. morio* (Young 1979, Kitchener & Coster 1981) and C. gouldii (Kitchener 1975). The pattern of reproduction appears to be similar in all species so far studied.

In males spermatogenesis occurs in spring and summer. Sperm are stored in the epididymes as the testes regress. Mating generally occurs in autumn and also occasionally during the hibernation period. However, Green (1965) noted an influx of males into a maternity colony of *E. vulturnus* in late spring after parturition and suggested that post-partum copulation was occurring.

All species are probably monoestrous. Females usually store sperm over the winter and use this to fertilize ova in early spring. Parturition occurs in late spring and early summer but varies with latitude and elevation through the influence of climatic factors on the timing of emergence from hibernation (Kitchener 1975, Phillips & Inwards 1981). Lactation is usually completed by the end of January or early February. Lactation has been found to finish later in *C. morio* than in the other species in the Brindabella Ranges near Canberra (Phillips & Inwards *pers. comm.*) and this is probably also the case in Tasmania (O'Neill 1984). Litter size is usually two in *N. geoffroyi*, *N. timoriensis* and *C. gouldii* and one in the other species (Strahan 1983).

DISCUSSION

The number of species of bats present in Tasmania is lower than elsewhere in eastern Australia but conforms with a trend of reduced numbers of species with increasing latitude (Hall

1981). Cave dwelling species are generally less numerous than forest roosting species and show a similar trend of decreasing number of species with increasing latitude (Hall 1981). In southern Australia there are numerous caves which have been poorly colonized by bats (Hall 1981) and it is thus perhaps not surprising that no cave dwelling species occur in Tasmania. All Tasmanian species except *N. timoriensis* occur on the adjacent southeastern mainland. *Nyctophilus timoriensis* has a patchy distribution across southern Australia including northern Victoria (Richards 1983b).

Contrary to what one might expect from Bergmann's rule, it was found that not all species exhibited a trend of increased size compared with populations from southeastern Australia. However, most of the data for southeastern Australia came from an area where the species are near the elevational limit of their range whereas the Tasmanian data are mostly from populations at lower elevations. Since body size is related to the size of insects eaten (O'Neill & Taylor in press), it is possible that the apparent contraction of the size range of species in Tasmania is related to a reduction in the size range of the prey available. We have no data on insect populations from southeastern Australia with which to test the hypothesis.

Several of the inferences made about the genus *Eptesicus* in Tasmania by Green & Rainbird (1984) (namely on the relative abundance and habitat preferences of the species) have been found to be incorrect. Green & Rainbird (1984) based their conclusions on evidence from museum collections. These collections tend to give a biased picture because of the predominance of specimens from populated areas. The main problem in undertaking detailed field studies of this genus lies in the difficulty of correctly identifying the three species. Hall & Richards (1979) listed the number of colour bands on the ventral hair and the shape of the lobe on the calcaneum as being features which could be used to separate the species in the field. These characters have not proved to be of any use in separating the Tasmanian specimens of this genus. The need to use internal characters for positive separation of the three species would hinder any detailed ecological study where individuals need to be released after capture. Simple antibody tests such as used by Herd (1983) may allow species identification without the need to sacrifice animals.

Our studies have shown that all species are widespread and none are rare. The two most important factors determining the numbers of bats are likely to be the abundance of food and the availability of roost sites. The complete clearing of natural vegetation for agricultural or urban development will probably be the most disruptive factor affecting bat populations. An understanding of the effects of the forest industry on bats is essential due to the large areas of habitat which are subject to disturbance. Limited forest exploitation may, in fact, be beneficial. We have found that bats were more abundant in a 12 year old regrowth forest than in an equivalent mature dry sclerophyll forest (Taylor & O'Neill 1986), probably due to a greater abundance of insects in the regrowth forest. However, bats do not appear to roost in regrowth forest and depend on the presence of old mature trees in the surrounding unlogged forest for roost sites (Taylor & Savva unpubl. data). Thus, in the future if most State forests have been converted to even aged stands, it is likely that bat populations will be severely reduced due to a shortage of suitable roost sites. The lack of preferences for specific vegetation types by Tasmanian bats should, however, act as a buffer against the effects of development in the short-term.

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(accepted 23 March 1987)

FERAL PIGS ON FLINDERS ISLAND

by M. Statham and M. Middleton

(with one table and one text-figure)

STATHAM, M. & MIDDLETON, M., 1987 (30:vi): Feral pigs on Flinders Island. *Pap. Proc. R. Soc. Tasm.*, 121: 121-124. ISSN 0080-4703. Tasmanian Department of Agriculture, P.O. Box 180, South Launceston (M.S.); and P.O. Box 5, Whitemark, Flinders Island (M.M.).

A survey of feral pigs on Flinders Island showed that three areas, the north and east coast lagoon areas, Strzelecki National Park and Darling Range have resident pig populations, with a total number of about 1 000 individuals. There is minimal damage to agricultural areas, or to the east coast lagoons but the National Park is being seriously damaged by pig activity.

Key Words: Feral pigs, Tasmania, Flinders Island.

INTRODUCTION

Feral pigs are now considered to be the most important mammalian pest of Australian agriculture (Pavlov 1983). They occur in most climatic regions of Australia but are limited in local distribution by the availability of food, access to water and reasonably undisturbed shelter. They are opportunistic omnivores, grazing on pasture and crops and eating any available carrion including dead pigs. In some areas feral pigs will kill and eat young lambs (Pavlov *et al.* 1981). As well as causing significant agricultural damage they provide a reservoir for potentially devastating diseases like foot and mouth should these occur in Australia.

Tasmania is fortunate in that its feral pig population is limited to Flinders Island although some early writers recorded their presence on mainland Tasmania (Plomley 1966).

As an aid to planning feral pig control and a guide to determining the feasibility of conducting a large-scale pig eradication campaign, a survey was carried out in May 1986. This consisted of an initial aerial survey of the east coast swamp lands followed by four days of ground inspections to determine pig densities and damage caused in the infested areas.

HISTORY

The origin of the Flinders Island feral pig population is not well documented. Some may have been released by early visitors to ensure a meat supply for themselves or they may have escaped following shipwrecks.

At least one of the introductions of pigs to Flinders Island also introduced a parasitic lungworm *Metastrongylus salmi* which is still found in some of the island's pigs (Gregory *pers. comm.* and this survey). This parasite does not occur in either the feral pig population of New South Wales (Giles 1980) or Australian domestic pigs (Seddon 1967). Unfortunately it cannot be used to trace the origin of the pigs as *Metastrongylus salmi* occurs in North and South America, South East Asia, China and Zaire (Soulsby 1982) and pigs from any of these areas could have introduced it.

One common story is that pigs of Asiatic origin were released when the ship *City of Foo Chow* went ashore on the northeast coast of Flinders Island in March 1877. Any pigs which had been on the boat could have been saved, as the crew had 30 hours to salvage material directly onto the beach. Unfortunately for the story, it was most unlikely that the *City of Foo Chow* had Asiatic pigs on board as it had sailed from London to Sydney with general cargo, then moved to Newcastle and loaded coal for Calcutta (Anon 1877). Any pigs which may have been on the ship would most likely have originated in New South Wales.

Early settlement occurred on many of the smaller islands in the Furneaux Group. Records of these early settlements show that many of the settlers kept pigs. The deliberate introduction of pigs into previously pig-free areas seems to have been a popular activity. As recently as the early 1970's, pigs were introduced to Babel Island, off the east coast of Flinders Island. These pigs were eradicated by Department of Agriculture staff with local assistance.

There are unconfirmed reports to suggest that domestic pigs have been released on some occasions either to help "upgrade" the feral popu-

lation, or when the owners decided not to keep pigs any longer.

A problem as interesting as the origin of Flinders Island pigs is the absence of feral pigs anywhere else in Tasmania. The first recorded release of pigs was made by Cook at Adventure Bay, Bruny Island in 1777 as part of his policy of introducing animals and plants to new lands. He "carried them (a boar and sow) about a mile within the woods at the head of the bay and there left them by the side of a fresh water brook" (Beaglehole 1967). This was in an attempt to hide the animals from the local natives who might have eaten them.

It is probable that his fears were not groundless, as no reference is made to pigs in the report of the Baudin expedition of 1802 (Plomley 1983), despite the presence of five zoologists who collected and observed on Bruny Island and mainland Tasmania for a period of ten days.

A reference to the presence of feral pigs was made by Robinson who noted "numerous traces of wild pigs" near Oatlands in November 1831 (Plomley 1966). It is possible that Robinson mistook the activities of a native animal for those of pigs, but there is a good pig habitat in that district, and many other parts of Tasmania to support a feral pig population and escapes must have occurred from some of the early pig keepers.

SURVEY RESULTS

Aerial Survey

A Cessna 172 was used in an attempt to count pigs in the east coast lagoon areas. Tree cover prevented any aerial survey of either the Darling Range or Strzelecki National Park. The survey was flown at 150 m altitude and 100 knots airspeed from 1100-1320 on 12 May 1986 with observers on both sides of the plane.

Only the major lagoon systems were surveyed, on the two to three hours of observation, and no attempt was made to cover systematically the whole of the north and east coast areas known to harbour feral pigs.

A total of only eight pigs were seen from the air, and in all cases they were moving rapidly from the edges of wet swamps towards scrub cover. It is probable that some pigs would have been missed if they had been stationary, and others would have moved into cover before they were seen. Extensive areas of pig damage were also noted from the air, which could be used to help define current pig distribution, but would be of little use in determining density as it was not possible to determine the age of the damage from the air. The low number

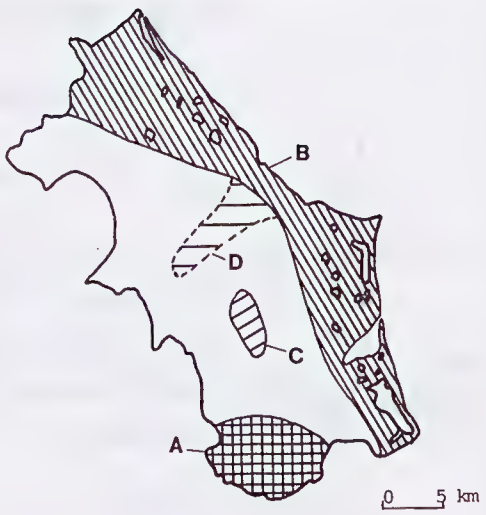

FIG. 1 — The distribution of feral pigs on Flinders Island. A. density medium to high; B. density medium; C. density low; D. pigs seen occasionally on farms.

of pigs seen during this survey is not atypical. During a feral pig control exercise in New South Wales, initial helicopter survey of both creeks and fixed grid counting indicated that only about 250 pigs were present in a defined area. Later, over 1000 pigs were shot and it was estimated that at least 15% still remained (Bryant *pers. comm.*)

A systematic survey of the pig affected areas of Flinders Island would probably have resulted in a larger number of pigs being sighted. This type of aerial survey however was found to be of little use in defining actual pig distribution or assessing the numbers present. It could at best be used to determine presence or absence of feral pigs in an area from either pig or damage sightings.

Ground Survey

A ground survey was conducted on foot and by vehicle in the four days (13-16 May) following the aerial survey. The areas examined were the major lagoon systems, plus the northeastern area of the Strzelecki National Park (Bob Smiths Gully, Big Hollow, Fannings Creek). Signs of pig activity and the presence of faeces were noted, plus any pig sightings. An attempt was made to estimate the age of damage signs from the colour and hardness of faeces and effects of recent rain and germination of seeds in disturbed areas. Pigs were recorded as

TABLE 1

Approximate size of affected areas and pig numbers.

Area	Size (km^2)	Density ($no./km^2$)*	Estimated Number
East coast	400	medium (1.5)	600
Strzelecki National Park	120	medium (3.0)	360
Darling Range	30	low (0.5)	15
Total	550		975

* Estimated using categories of Mitchell *et al.* (1982).

being present if fresh signs were noted. It was evident from this survey that feral pigs cause only minor damage in most areas. If however they find an attractive food source the area is revisited each night for several nights, sometimes causing enough pasture damage to necessitate levelling and resowing. The ground survey was used to assess relative densities to allow an estimate of the number of feral pigs present.

DISTRIBUTION

Feral pig distribution (fig. 1) was plotted from data gathered by Department of Agriculture staff and National Parks and Wildlife Service rangers stationed on Flinders Island. The original data were from personal observations of pig damage, pig sightings and investigations of farmer reports.

There are three areas on Flinders Island where pigs occur regularly: the east coast, Darling Range, and Strzelecki National Park. The east coast is generally low lying (<20 m a.s.l.) with both permanent and intermittent swamps. Vegetation varies from tussock grasslands (*Poa* spp.) through sedges and heaths to woodlands and open forest. Low lying swampy ground supports species such as *Melaleuca ericifolia*, which can occur in pure stands up to about 12 m. The low ridges between lagoons carry eucalypts to about 15 m (*Eucalyptus globulus* where conditions are favourable and *E. nitida* under harsher conditions). Dryer elevated areas carry tea-tree species, mainly *Leptospermum laevigatum* and *L. glaucescens*. *Banksia marginata* is widespread. The vegetation provides good cover for pigs as it is very dense at ground level. The northern part of this area contains some higher points (Mt Killiecrankie — 316 m, Mt Boyes — 274 m), the vegetation being dominated by *Casuarina monilifera* and *Eucalyptus nitida* on acid soils, and *Casuarina stricta* on limestone. It contains fewer swamps and more farmland. The density of pigs in the east coast areas fluctuates with the amount of water in the swamps, with pigs preferring wetter areas.

The second area where pigs occur is the Darling Range in the centre of the island. This is an area of dry sclerophyll forest with wet sclerophyll species in the gullies. The habitat in the Darling Range would generally not favour pigs, the area being generally drier, with very few permanent watercourses and generally harder, woody ground plants. Reports of more than occasional pig damage in this range have only become common in the last two years and pigs may have moved into the Darling Range following extensive fires on the east coast in the summer of 1982-1983.

The third major population of pigs occurs in the Strzelecki National Park where they range from sea level to the peak tops (756 m). The Strzelecki Range vegetation consists of dry sclerophyll forest at low levels and wet sclerophyll forest higher up with areas of mixed forest in between. The area has many deep sheltered gullies carrying lush vegetation of the higher rainfall type including tree ferns (*Cyathea australis* and *Dicksonia antarctica*) to about 8 m. The gullies carry *Eucalyptus globulus* and *E. viminalis* to about 40 m, and other species of restricted distribution such as sassafras (*Atherospermum moschatum*), blackwood (*Acacia melanoxylon*) and musk (*Olearia argophylla*). Undershrubs include mountain pepper (*Tasmannia lanceolata*), cheesewood (*Pittosporum bicolor*) and lemon bottlebrush (*Callistemon pallidus*). The gullies are the areas in which pigs are most active and where visible pig damage is quite extensive.

Feral pigs are occasionally seen on farms in the central north of the island (fig. 1, area 1A),

presumably as a result of the animals following drainage lines.

PIG DENSITY

Pig densities were estimated for the three areas using the criteria developed by Mitchell *et al.* (1982).

Pig sightings could not be used as a criterion for density estimation in the National Park due to the thickness of vegetation which both limited visibility and made penetration noisy, with pigs moving before they were sighted. There was an extensive network of pig runways throughout the Park and signs of pigs were abundant in many areas. The areas affected by pigs and estimated numbers are shown in table 1.

FERAL PIG DAMAGE AND CONTROL

Feral pigs usually invade agricultural areas adjacent to the National Park and east coast swamps in winter. Damage is considered by farmers to be minor as it is restricted to rooting in pasture adjacent to bush edges. The animals are apparently digging dock (*Rumex*) and thistle roots or rolling turf to expose grubs. The annual total pasture area damaged is estimated to be less than 50 ha. Feral pigs are reported to visit paddocks where ewes are lambing but there are no reports of lambs being killed, although pigs will take any carcasses left near the bush. It is possible that the population is low enough for individuals to satisfy their appetite without killing lambs.

In non-agricultural areas there appears to be little long-term damage done in the low lying east coast lagoon country, but the Strzelecki National Park is being severely damaged. Extensive pig rooting in the moist rich gullies of the Park leads to water erosion and loss of regenerating forest plants. Bracken fern (*Pteridium esculentum*) flourishes in this pig-disturbed environment and takes over large areas forming pure impenetrable stands to about 4 m, and preventing light reaching the forest floor.

Control of feral pigs in agricultural areas is by shooting. There are enough hunters interested in pig shooting to effect sufficient control to satisfy farmers demands. There is also a moderate hunting pressure on pigs along the east and north coasts. No pig shooting has occurred in the National Park, although if this was done under permit, pig populations in some parts of the Park would be significantly reduced.

ACKNOWLEDGEMENTS

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(accepted 24 March 1987)

STREAMFLOW CHARACTERISTICS OF NORTHEASTERN TASMANIA: II. HYDRAULIC GEOMETRY

by A.D. Knighton

(with three tables and six text-figures)

KNIGHTON, A.D., 1987 (30:vi): Streamflow characteristics of northeastern Tasmania: II. Hydraulic geometry. *Pap. Proc. R. Soc. Tasm.*, 121: 125-135. ISSN 0080-4703. Department of Geography, University of Sheffield, Sheffield, SI0 2TN, United Kingdom.

Relationships describing the adjustment of water-surface width, mean depth and mean velocity to increasing discharge are calculated for eleven sections in northeastern Tasmania. The at-a-station graphs of two sections display distinct discontinuities related, however, to different causes — sub-bankfull channelization and the attainment of overbank stage. Despite intra-reach and inter-fluvial variations in hydraulic geometry, two types of response seem to be dominant, characterised by a high rate of change of either depth or velocity. Two sections do not fit into this pattern and, significantly, they tend to plot poorly on downstream graphs.

Bankfull discharge probably lies between Q1.11 and Q2 at most sites, so both flows are used as reference discharges in analyses of downstream adjustment at the regional scale. The relations at Q1.11 and Q2 are quite similar and they are within the envelope defined by results from other areas. However, the data base is small and the scatter is large enough to render the velocity-discharge relation non-significant. The main residual from regression is the station on the South Esk at Perth which is used for discharge measurements at higher flows. Nevertheless, the hydraulic geometry equations enable estimates to be made of channel flow properties at ungauged sites within the northeastern river system.
Key Words: Tasmania, stream flow, hydraulic geometry, bankfull discharge.

INTRODUCTION

This paper is a companion to Part I (Knighton 1987) which dealt with the variation of several flood discharges at the regional scale. Here, attention focuses on the adjustment within channels to changing discharge at both local and regional scales, using hydraulic geometry as the analytical method.

Adjustments to the internal geometry of the fluvial system involve complex interactions amongst a large number of variables, which cannot be specified by a closed set of equations. Consequently some degree of abstraction or simplification becomes necessary. Certain aspects of the adjustment process can be approached through the technique known as "hydraulic geometry" which was introduced by Leopold & Maddock (1953) as a means for providing a quantitative description of river behaviour. It rests on two assumptions: that discharge (Q) is the dominant independent variable, and that dependent variables such as width (w), mean depth (d) and mean velocity (v) are related to it by simple power functions:

$$w = a\,Q^{b} \quad (1)$$
$$d = c\,Q^{f} \quad (2)$$
$$v = k\,Q^{m} \quad (3)$$

Given the mass continuity equation, one of the physical relations which a river must satisfy:

$$Q = w.d.v \quad (4)$$

it follows that:

$$b + f + m = 1 \quad (5)$$
$$a.c.k = 1 \quad (6)$$

where b, f and m are the rates of change of the respective dependent variables, and a, c and k are the corresponding intercept values at unit discharge. The methodology can be applied in two contexts — at particular cross-sections ("at-a-station" hydraulic geometry) or along and between rivers ("downstream" hydraulic geometry). In the first, emphasis is placed on temporal changes in flow geometry as discharge fluctuates within the bankfull channel, while the second is concerned with spatial adjustments of flow and channel geometry at a constant frequency of discharge. Both are considered in this paper.

The data have been extracted mostly from the gauging records of the Rivers and Water Supply Commission of Tasmania. Those records were compiled to provide discharge measurements at established gauging stations and not for the

TABLE 1

At-a-station relations.

River	Equation constants						Bed material	Sample size
	a	b	c	f	k	m		
Cascade (C)	5.03	0.22	0.43	0.28	0.47	0.50	Gravel and coarse sand	9
George (G):							Mostly sand with	17
(i) Low-flow section	13.89	0.28	0.20	0.53	0.36	0.19	occasional bedrock	13
(ii) Cableway section	11.38	0.20	0.70	0.27	0.12	0.53	exposures	
Great Forester (GF)	10.29	0.22	0.29	0.50	0.33	0.28	Mostly coarse sand	11
North Esk (NE):							Predominantly gravel	25
$Q \leq 30\ m^3\ s^{-1}$	8.65	0.15	0.59	0.22	0.20	0.63	but a large range of sizes	(23)
$Q \geq 30\ m^3\ s^{-1}$	0.90	0.83	1.12	0.03	1.00	0.14	from medium sand to small boulders	(4)
Ransom (Ra)	6.95	0.36	0.38	0.27	0.38	0.37	Gravel and boulders with coarse sand beneath	12
Ringarooma (R):							Gravel with sand and	33
$Q \leq 13\ m^3\ s^{-1}$	8.64	0.40	0.24	0.38	0.48	0.22	occasional boulders	(19)
$Q \geq 13\ m^3\ s^{-1}$	18.98	0.09	0.13	0.63	0.41	0.28		(15)
South Esk at Llewellyn (SE_L):							Gravel and boulders	
(i) Low-flow section	15.52	0.12	0.35	0.30	0.18	0.58		13
(ii) Bonneys Plain	18.17	0.12	0.23	0.53	0.24	0.35		16
(iii) Cableway section	29.24	0.17	1.49	0.21	0.02	0.62		17
South Esk at Perth (SE_P)	17.63	0.33	1.62	0.13	0.04	0.54	Mixture of gravel, sand and silt	11

Symbols: $w = a\ Q^b$, $d = c\ Q^f$, $v = k\ Q^m$.

purpose of analysing flow and channel adjustment. Consequently care had to be exercised in building up the data base — sections containing artificial structures were excluded; individual gaugings which did not adequately specify the water-surface edge were ignored; the remaining records for each station were sampled in a stratified way to ensure a representative range of discharges and, whenever possible, measurements made of width, depth and velocity at the same discharge were checked as to their consistency. At some gauging station sites slightly different sections are used at different discharges, so whether average values were obtained for several sections or results from only one section considered depended on the range of flows covered, with inclusion of the median annual flood (Q_2) being critical. That discharge forms the basis of the regional-scale analysis.

AT-A-STATION RELATIONS

As discharge varies at an individual cross-section, changes occur in water-surface width, mean flow depth, velocity and such variables as flow resistance and bed shear stress. To a large extent these changes in flow characteristics are governed by the prevailing dimensions and shape of the channel but they can themselves be altered by the flow, especially during flood discharges. Analysis is usually limited to sub-bankfull flows because of the rapid increase in water-surface width and resultant discontinuity in hydraulic behaviour commonly associated with overtopping of the channel banks and occupation of the adjoining flood-plain. Here, however, only one section was severely affected by such changes.

The stations used in this study are listed in table 1, together with the relevant coefficient and exponent values. All those values are statistically significant at the 95% level and for the most part

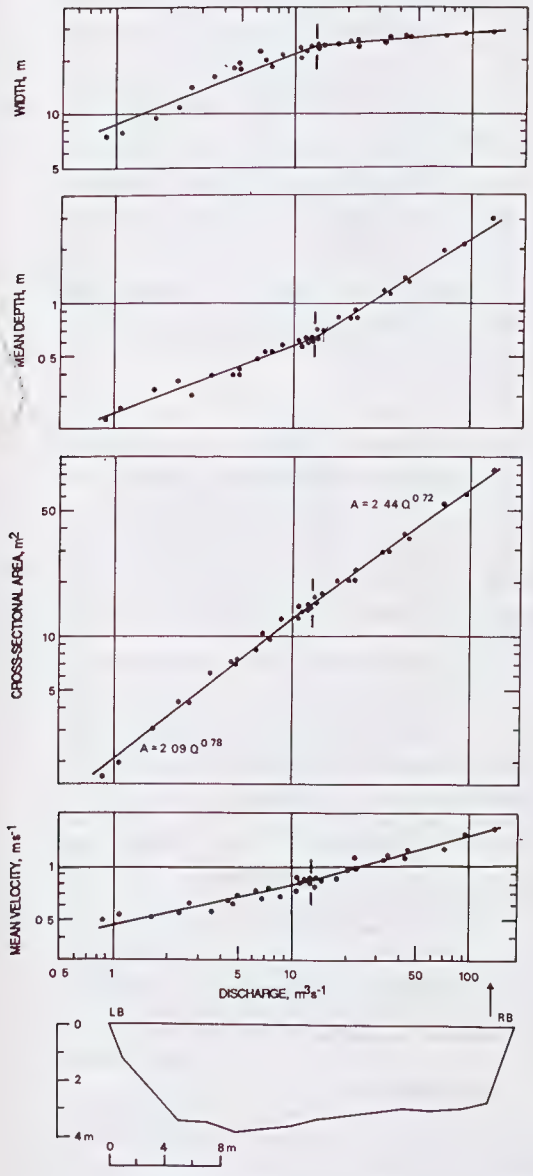


FIG. 1 — At-a-station hydraulic geometry, Moorina, Ringarooma River.

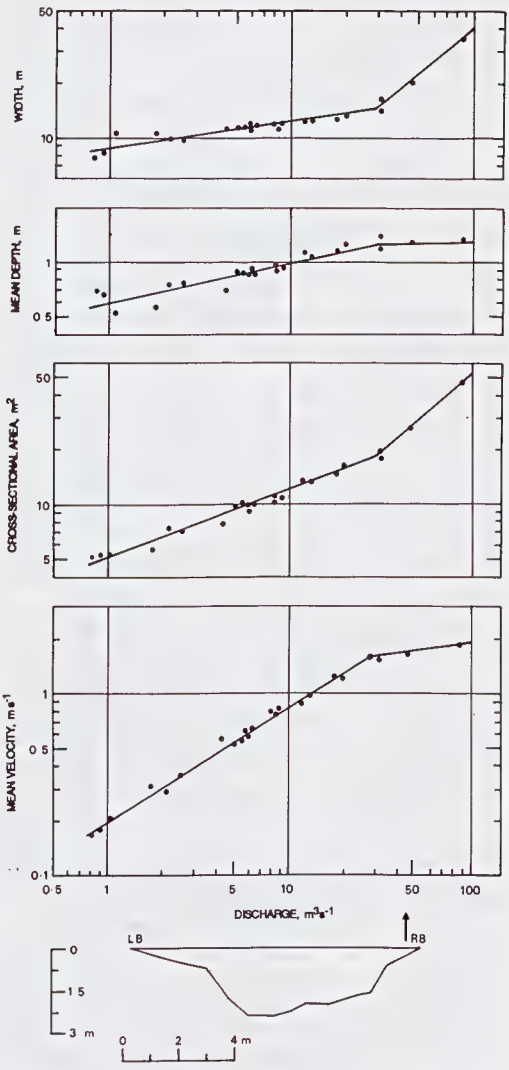


FIG. 2 — At-a-station hydraulic geometry, Ballroom, North Esk River.

the log-linear plots are well defined with only small amounts of scatter about regression lines. Scatter is a common feature of many at-a-station graphs and it can come from various sources — measurement error, analytical error, random variation, and systematic change to the channel (Knighton 1977). In the present case where the cross-sections have relatively stable forms the main source was random fluctuation about a modal state, although the data sets at two sections had to be subdivided because of explicit discontinuities (figs 1 and 2) which however were not produced by the same channel condition.

The discontinuity at the Ringarooma section was related to low-flow channelization (the bed of

the main channel contained a subordinate section), with a distinct change in behaviour at a discharge of about 13 $m^3 s^{-1}$ (fig. 1). At lower flows the entire bed width of 22 m was not occupied so that as discharge increased water-surface width increased rapidly at the relatively high rate of 0.40. In this flow range surface width expansion was preferred to deepening as the means of accommodating larger flow cross-sections, although the distribution of points on the width- and depth-discharge graphs suggests some inconsistencies in the way that was achieved. Above 13 $m^3 s^{-1}$ the trends are better defined. Following occupation of the entire bed width the flow was contained within relatively steep banks so that width adjustment was limited. In compensation depth became more responsive, increasing at a rate higher than any other in table 1. Throughout this marked transition in width and depth behaviour the cross-sectional area of flow and average velocity were affected surprisingly little, their hydraulic relations showing only slight inflections at the transitional flow. Indeed, although the change in velocity was relatively conservative, it was well defined for such an adjustable variable. This type of discontinuity in hydraulic geometry has been reported elsewhere (Lewis 1966) and Richards (1976) has raised the possibility of more than one break of slope in at-a-station graphs, particularly where bank profiles are highly irregular. Here, however, there was only one break and that occurred at a flow which on average is equalled or exceeded 20% of the time. Discharges below 13 $m^3 s^{-1}$ are expected to perform only small amounts of erosional or transportational work at this section.

The discontinuity at the North Esk section occurs at a much higher discharge of about 30 $m^3 s^{-1}$ (fig. 2), a flow with an approximate frequency of 1.5%. Up to that value changes in velocity accommodate most of the increase in discharge, with depth showing a surprisingly limited capacity for adjustment. Also, the depth graph has the largest scatter but, considering the data were a sample of nine years of record, small changes in bed elevation are to be expected. The upper flow range is characterised by a two-fold increase in the rate of change of cross-sectional area caused almost entirely by a pronounced widening of the stream. This, together with the form of the cross-section at 44.5 $m^3 s^{-1}$ (fig. 2), is evidence that the transitional flow corresponds to bankfull discharge. The much slower rate of change of velocity after the break is attributed to the effects of increased resistance as the flow spills over onto the adjoining flood-plain with its dense vegetation. Unfortunately there are only two data points at discharges much above 30 $m^3 s^{-1}$ so that the higher flow response is less certain but extensive patches of fine to coarse sand on the flood-plain suggest frequent overbank stages. If 30 $m^3 s^{-1}$ is the approximate bankfull discharge, then it is only slightly more frequent than in other humid temperate areas. Bankfull discharge has a modal recurrence interval of about 1.5 years on the annual maximum series according to North American data (Williams 1978a), while a discharge of 30 $m^3 s^{-1}$ has a recurrence interval of 1.13 years at this section. The duration of overbank flooding in England and Wales is two days a year on average (Nixon 1959), whereas here it is five days a year. Williams (1978a) developed a regression equation for estimating bankfull discharge (Q_b) based on 233 observations,

$$Q_b = 4\, A_b^{1.21}\, s^{0.28} \qquad (7)$$

where A_b is channel capacity at bankfull and s is slope. Applied to North Esk data, it gives a value of 28 $m^3 s^{-1}$. However, this equation does not apply in eastern Australia (Warner, pers. comm.) and in the Cumberland Basin of New South Wales the return periods of bankfull discharge lie mainly in the range of 4-10 years on the annual series (Pickup & Warner 1976).

The type of discontinuity represented by the North Esk results is not present to any marked extent in any of the graphs from other sections, even though the data ranges include flows which are larger than the median annual flood (Q_2). The highest flow at the Ringarooma section has an estimated recurrence interval of nearly three years but it is still contained within the confines of the channel (fig. 1). The cross-sectional profiles at the South Esk and George stations contain shelves which might be interpreted as bankfull levels (figs 3 and 4) but neither set of graphs shows much tendency toward discontinuity. In New South Wales rivers, Woodyer (1968) identified up to three such shelves or benches, the highest one representing the present flood-plain level. There, bankfull frequency ranged from 1.24 to 2.69 years.

The Perth station has been chosen to illustrate a high-flow section, its nearest equivalent being the cableway section at Llewellyn. The flow range extends from just above mean annual discharge to almost Q_5 but unfortunately there is a lack of adequate measurements between 200 and 500 $m^3 s^{-1}$. The cross-section (fig. 3A) has two steps in the right bank profile, an inner smaller one reached at a discharge of approximately 130 $m^3 s^{-1}$ and an outer more continuous one reached at about 480 $m^3 s^{-1}$. The latter is the more likely bankfull level but its attainment seems to produce no marked deviation

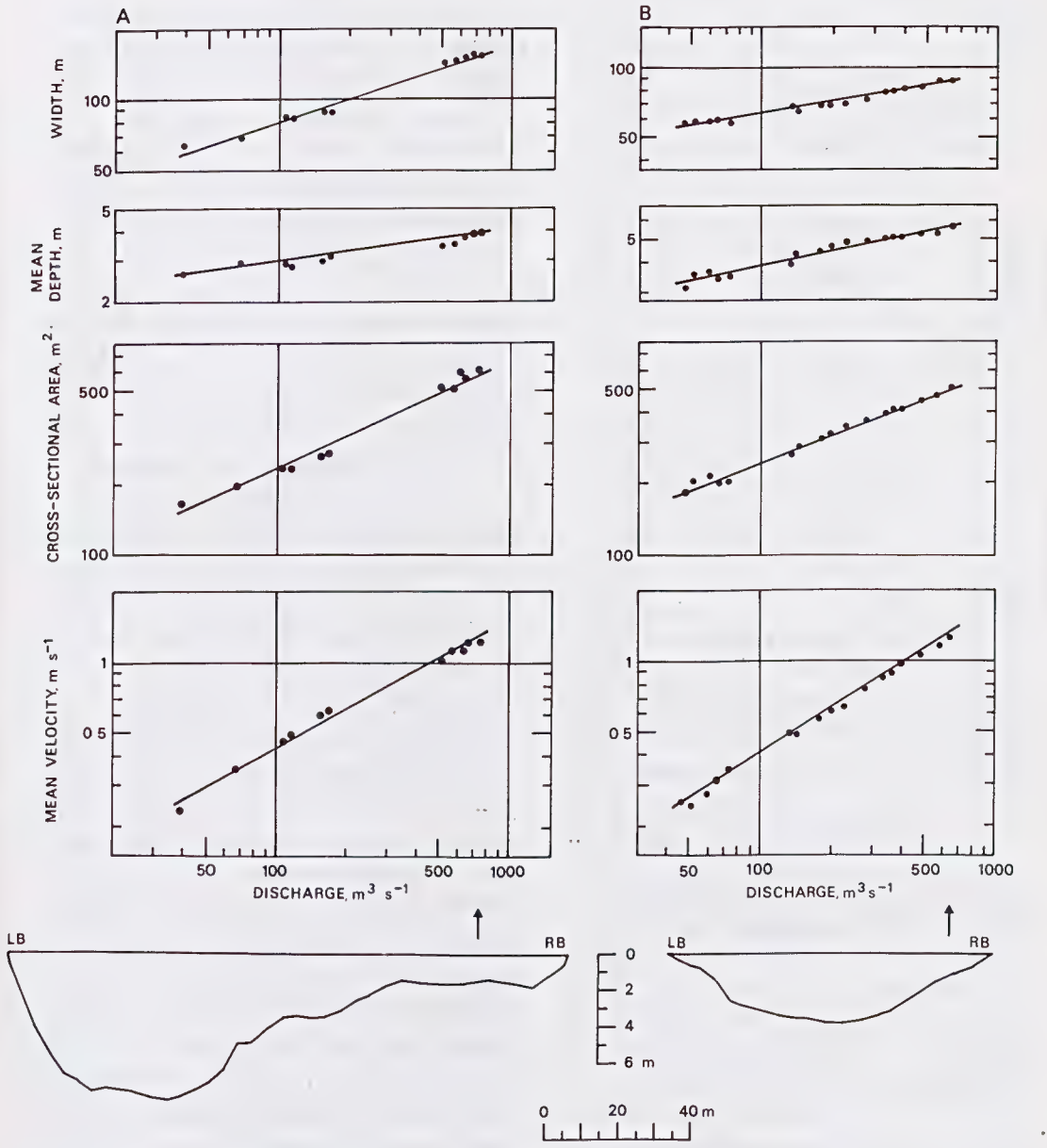


FIG. 3 — At-a-station hydraulic geometry, South Esk River at Perth (A) and Llewellyn (B), cableway sections.

from log-linearity in any of the variables at this very stable section where $Q_{1.11}$ and Q_2 are respectively 174 and 491 $m^3 s^{-1}$. However, the main characteristics of the hydraulic geometry are very large depth and very low velocity intercept values (table 1). In compensation velocity adjusts relatively quickly to changing discharge so that by about Q_2 it has reached 1 $m^3 s^{-1}$. These features are shared by

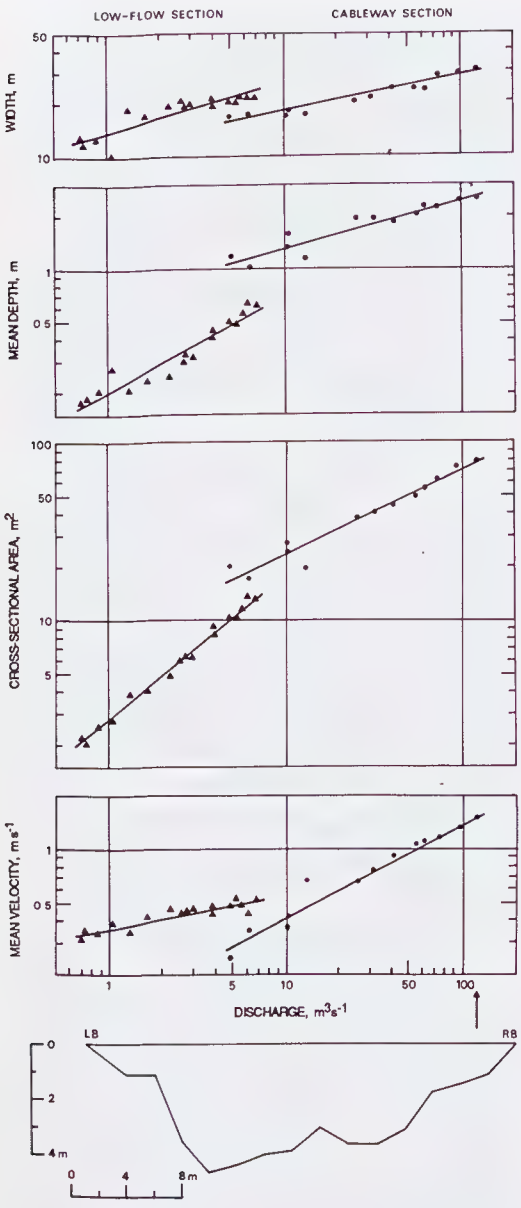


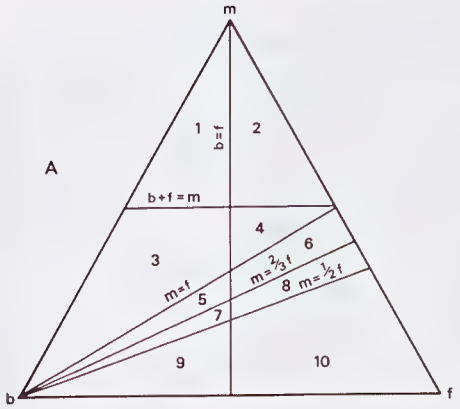
FIG. 4 — At-a-station hydraulic geometry, low-flow and cableway sections at St Helens, George River.

other high-flow sections at Llewellyn (fig. 3B) and, to a lesser extent, on the George (fig. 4) and imply limited capacity to transport coarser bed materials until quite large discharges are reached.

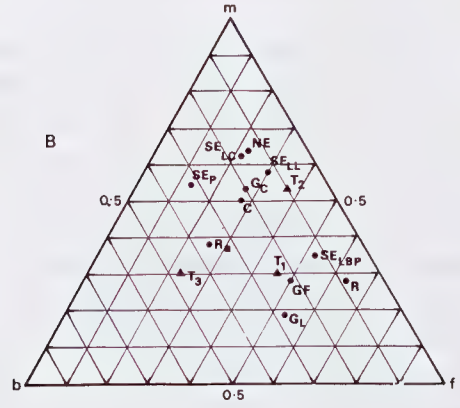
Local scale variations in hydraulic geometry are not uncommon. Differences have been found between straight, curved and divided reaches (Knighton 1975), between pool and riffle sections (Richards 1977), and around a meander bend (Bridge & Jarvis 1982). Here they are reflected in the variable behaviour of sections used in the measurement of discharge over different ranges. On the George the sections are about 150 m apart but their hydraulic relations are quite distinct, although there is a hint of continuity in the width-discharge graph (fig. 4). The main difference lies in the much higher rate of change of velocity, and lower rate of change of depth, at the high-flow section. Its depth and velocity graphs also have quite a lot of scatter at the lower end of the range, suggesting some inconsistency as this sandy-bed section begins to fill. In contrast to the George sections, the low-flow and cableway sections of the South Esk at Llewellyn differ largely in terms of intercept values rather than rates of change (table 1).

The results in table 1 suggest a wide range of responses at both local and regional levels. Rhodes (1977) suggested the method of plotting sets of b-f-m exponents on a triaxial graph, subdividing the diagram into ten channel types delimited by distinct hydraulic criteria (fig. 5A). A plot of 315 data sets revealed the following order in terms of decreasing frequency of occurrence: 2-6-10-8-4-3-5-7-1-9. Five of the sections — NE, C, G_C, SE_{LL}, SE_{LC} — occur in region 2 (fig. 5B), which is the most common and is characterised by m>f>b and m>f+b. Such channels are regarded as quite stable and are thought to experience large decreases in resistance with increased discharge. Four of the remaining six sections are also relatively common types — 6 (SE_{LBP}), 10 (R, G_L), 8 (GF) — with the Bonneys Plain section in the same region as the most probable state of channel morphology according to the theoretical developments of Langbein & Leopold (1964). All have f>b and f>m, indicating that depth accommodates most of the increase in discharge. That may increase the ability to entrain bed material, because entrainment depends on shear stress which is a direct function of depth, and to drown out resistance elements on the bed. The two remaining sections (SE_P — region 1, Ra — region 3) are atypical in having b>f so that the width-depth ratio increases with discharge. Nevertheless, despite the high rate of change of width which tends to introduce marginal areas of high resistance to the flow cross-section (Knighton 1975), these sections and particularly SE_P adjust their velocities quite rapidly.

Two theoretical developments deal explicitly with at-a-station hydraulic geometry; threshold



1	b > f	m > ½	f < m	⅔f < m	½f < m
2	b < f	m > ½	..	..	
3	b > f	m < ½	.	..	..
4	b < f	..		..	.
5	b > f	..	$\overline{f} > \overline{m}$	..	..
6	b < f	.		.	.
7	b > f	..	..	$\overline{⅔f} > \overline{m}$	.
8	b < f	.		.	
9	b > f	..	..	..	$\overline{½f} > \overline{m}$
10	b < f	.		.	



C	Cascade
G_L	George (low-flow)
G_C	George (cableway)
GF	Great Forester
NE	North Esk ($Q \leq 30\ m^3\ s^{-1}$)
R_a	Ransom
R	Ringarooma ($Q \geq 13\ m^3\ s^{-1}$)
SE_{LL}	South Esk at Llewellyn (low-flow)
SE_{LBP}	South Esk at Llewellyn (Bonneys Plain)
SE_{LC}	South Esk at Llewellyn (cableway)
SE_P	South Esk at Perth
T_1:	Threshold theory
T_2:	Minimum variance theory: cohesive but non-vertical banks, non-cohesive bed
T_3:	Minimum variance theory: non-cohesive and easily eroded boundary

FIG. 5 — Triaxial diagrams showing (A) the ten channel types defined by Rhodes (1977) and (B) a plot of at-a-station exponents. Rates of change of width (b), depth (f) and velocity (m) increase respectively towards bottom left, bottom right and top.

theory which applies to small gravel streams whose boundaries at bankfull discharge are on the threshold of motion (Li *et al.* 1976), and minimum variance theory which is probabilistic rather than deterministic (Langbein 1964). The theoretical states are plotted on the b-f-m diagram (fig. 5B), with two conditions applied through minimum variance theory (Williams 1978b). It is unlikely that the study sections can be classified as threshold channels, although some may have only limited sediment transport up to bankfull flow, or that they have boundaries which are entirely non-cohesive. Consequently T_2 is the most applicable state and it lies close to the five sections in region 2 (fig. 5B). However, in overall terms, the most interesting feature of the plot is the tendency for two clusters to form, characterised by rapid adjustment of either velocity (NE, SE_{LC}, SE_{LL}, SE_P, G_C, C) or depth (R, G_L, SE_{LBP}, GF). Whether there is any significance in T_2 and T_1 being approximately associated with these clusters is not known.

At-a-station hydraulic geometry can be strongly influenced by local conditions such as bank material composition. A high silt-clay content in bank material maintains steep bank angles and high resistance to erosion, both of which lead to low width exponents (Knighton 1974). It is perhaps significant that the most consistent set of at-a-station relations, that of Wolman (1955), was obtained for a single stream flowing through

TABLE 2

Downstream relations, northeastern Tasmania.

Discharge	Hydraulic relation	Correlation coefficient	Standard error of estimate
Q_2	$w = 3.80\ Q^{0.49}$	0.93	0.16
	$d = 0.32\ Q^{0.43}$	0.98	0.08
	$A = 1.22\ Q^{0.92}$	0.99	0.11
	$v = 0.82\ Q^{0.08}$	0.55	0.12
$Q_{1.11}$	(i) with North Esk data		
	$w = 4.0\ Q^{0.50}$	0.93	0.14
	$d = 0.33\ Q^{0.45}$	0.98	0.06
	$A = 1.33\ Q^{0.95}$	0.98	0.14
	$v = 0.75\ Q^{0.05}$	0.26	0.14
	(ii) without North Esk data		
	$w = 4.24\ Q^{0.05}$	0.95	0.13
	$d = 0.33\ Q^{0.45}$	0.99	0.06
	$A = 1.40\ Q^{0.95}$	0.99	0.10
	$v = 0.71\ Q^{0.05}$	0.36	0.11

uniformly cohesive bank material. There is no such consistency here since the results indicate differences both within the same reach and between rivers. The effects of bank material composition are still to be explored. The remaining question is whether any trends can be discerned in the other context, that of downstream hydraulic adjustment.

DOWNSTREAM RELATIONS

The selection of a reference discharge is essential for defining downstream trends since it provides the basis for comparing sections at different positions in the drainage network hierarchy. Various discharges have been used, including mean annual flow (Leopold & Maddock 1953), the 50%, 15% and 2% duration flows (Wolman 1955) and the median annual flood (Bray 1982). Geomorphologists have tended to favour bankfull discharge because of its assumed channel-forming significance but the bankfull state cannot always be defined and is not necessarily associated with a particular flow frequency (Williams 1978a). However, it is probably most appropriate to choose a discharge close to bankfull because flows in that range seem cumulatively to perform most work as regards sediment transport (Wolman & Miller 1960, Andrews 1980, Webb & Walling 1982) and are therefore more likely to be responsible for shaping the channel. The at-a-station analysis suggested that the bankfull condition at the study sections lies somewhere between $Q_{1.11}$ and Q_2, with a tendency toward the latter. Consequently downstream relations are obtained for both flows but with more emphasis on Q_2. This is in keeping with Bray's (1982) analysis of Alberta gravel rivers, the most comprehensive so far at the regional scale.

The following procedure was used. Firstly, the flood flows were determined from analyses of annual maximum series except at the Cascade, Great Forester, Ransom and Ringarooma stations where records were not long enough. There the relevant flows were estimated from the regional drainage area relationships (Knighton 1987). Secondly, the width, depth and velocity corresponding to the given discharge were calculated from the at-a-station equations for each section to yield the data required for the regional-scale regression analysis. Several qualifications need to be made. The low-flow sections on the George and South Esk (Llewellyn) were excluded by their very nature. The North Esk results for Q_2 were not included because of the marked discontinuity just above $Q_{1.11}$ (fig. 2) and the small number of points in the upper flow range. The hydraulic data for the South Esk at Llewellyn are averages of the Bonneys Plain and cableway sections.

The cross-sectional geometry relationships for the median annual flood are all statistically significant at the 95% level (table 2), with the depth-

discharge relation being the most consistent (fig. 6). If width–depth ratio (w/d) is taken as an appropriate parameter of channel shape, the results indicate that channels become more rectangular with increasing discharge but the tendency is only slight. In common with most river systems, cross-sectional area (w.d) accommodates most of the increase in discharge with velocity changing very little. Indeed the velocity–discharge relation is not significant but, since velocity is one of the most inherently variable parameters and the rate of change is low, the lack of significance is not unexpected. Bray (1982) found that, although velocity increased with discharge at the regional scale, it might decrease, remain constant or increase along individual rivers.

There is quite a large scatter about regression lines (fig. 6), although it is less than might have been expected considering the small number of data points and the wide range of physiographic conditions which they represent. The most conspicuous residual is the South Esk at Perth which has a wider and shallower section with a lower velocity than the distribution of points would otherwise suggest. The Ransom is also quite a prominent residual and it is perhaps significant that these two stations tend to plot apart from the others on the triaxial diagram of at-a-station conditions (fig. 5B).

The hydraulic relations at $Q_{1.11}$ were calculated without and with the North Esk data (table 2), in order respectively to enable a direct comparison with the Q_2 results and to increase the small data base. Despite the difference in discharge magnitude, the average of $Q_{1.11}/Q_2$ being 0.42, the equations for $Q_{1.11}$ and Q_2 are quite similar, particularly as regards the depth-discharge relation which is again the most consistent. The main difference lies in the width and velocity intercept values. It is also striking that inclusion of the North Esk data produces no significant change in coefficients or exponents, the latter of which remain exactly the same. However, the North Esk was the largest residual, being characterised by a low width and depth and a high velocity, and the results are slightly poorer in statistical terms.

Table 3 shows that the results from north-eastern Tasmania overlap those from other areas, with the strongest similarity being in the width–discharge relation which is commonly regarded as the most regular. Depth tends to adjust more rapidly and velocity more slowly in this area than elsewhere but the differences are relatively small. Indeed there is quite a close affinity between the Q_2 relations and those for British gravel-bed rivers. It

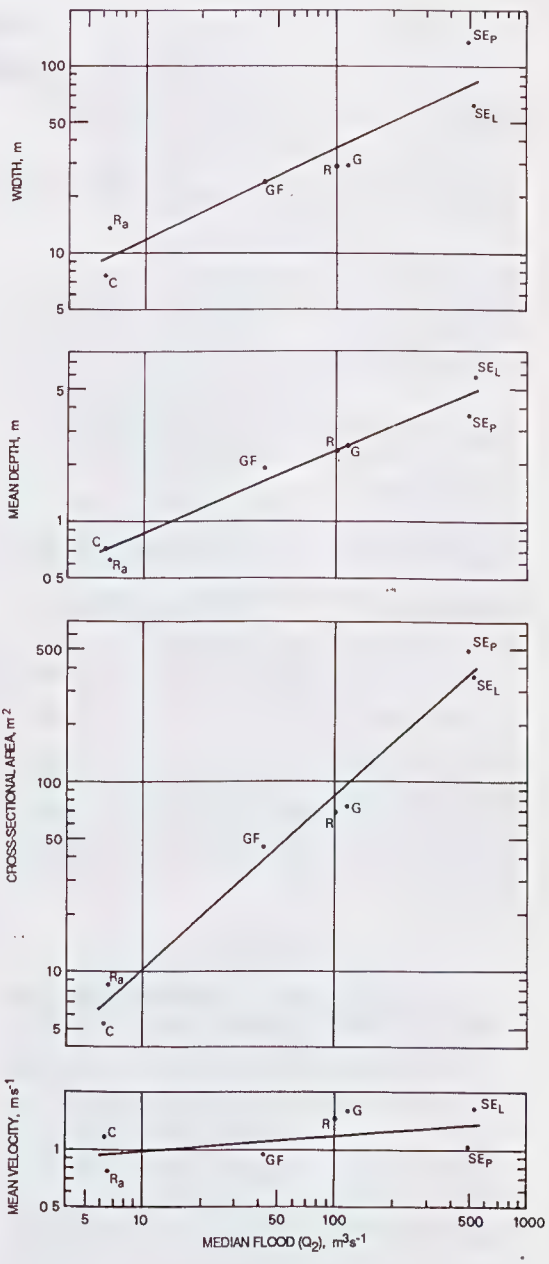


FIG. 6 — Downstream hydraulic geometry at the median annual flood.

is interesting also that the Tasmanian results are probably the set closest to Parker's (1979) theoretical predictions which, unlike most, take account of bank stability. Despite the small data base,

TABLE 3

Downstream hydraulic geometry relations.

Source	Location/applicable conditions	Dis-charge	Equation constants a	b	c	f	k	m
This study	Northeastern Tasmania	Q_2	3.80	0.49	0.32	0.43	0.82	0.08
		$Q_{1.11}$	4.00	0.50	0.33	0.45	0.75	0.05
(i) Empirical								
Charlton *et al.* (1978)	British gravel-bed rivers	Q_b	3.74	0.45	0.31	0.40	0.86	0.15
Bray (1982)	Alberta gravel-bed rivers	Q_2	4.79	0.53	0.26	0.33	0.80	0.14
* Andrews (1984)	Colorado gravel-bed rivers:							
	— thick bank vegetation	Q_b	3.91	0.48	0.49	0.37	0.52	0.15
	— thin bank vegetation	Q_b	4.94	0.48	0.48	0.38	0.42	0.14
Rundquist (1975)	Rivers and canals with gravel and sand beds	Q_b	4.39	0.52	0.38	0.32	0.60	0.16
(ii) Theoretical								
Li *et al.* (1976)	Threshold theory	Q_b		0.46		0.46		0.14
* Parker (1979)	Momentum diffusion, gravel rivers	Q_b	4.40	0.50	0.25	0.42	0.91	0.08
Chang (1980)	Minimum stream power, gravel	Q_b		0.47		0.42		0.11

Discharge defined as bankfull (Q_b) or the one having a recurrence interval of 2 (Q_2) or 1.11 ($Q_{1.11}$) years.

Symbols: $w = a\ Q^b$, $d = c\ Q^f$, $v = k\ Q^m$. * Analysis in terms of dimensionless variables.

therefore, the downstream relations seem to be of the right order of magnitude and may be used to estimate width, depth and velocity at various discharges and locations within the northeast river system.

CONCLUSION

Hydraulic geometry is essentially two topics in one. At-a-station analysis focuses on the changes in hydraulic parameters as discharge varies through time. Here, it indicates a wide range of responses both within and between study reaches but, when exponent sets are plotted on a triaxial diagram (fig. 5), nine out of the eleven sections prove to be relatively common types. They tend to form two clusters, characterised by a high rate of change of either depth or velocity. The two remaining sections are set apart by their greater inclination toward width adjustment and it may be this distinctive behaviour which makes them the largest residuals in downstream plots (fig. 6).

The at-a-station graphs of two sections contain sharp discontinuities (figs 1 and 2) but they do not reflect the same channel condition. One is related to occupation of the entire bed width at intermediate flows, while the other is associated with the more familiar rapid expansion of width at overbank stage. However, only at that section does the attainment of bankfull produce a significant change in the rates of adjustment of hydraulic variables. Although there is variation from one station to another, bankfull discharge seems to have a recurrence interval between 1.11 and 2 years. $Q_{1.11}$ and Q_2 were therefore used as the reference discharges in a downstream analysis.

Downstream hydraulic geometry predicts the adjustment of channel dimensions and flow velocity to an imposed discharge. There is little difference between the relations for $Q_{1.11}$ and Q_2, and they are well within the envelope formed by results from elsewhere. However, the data base is small and no great accuracy can be claimed until more data are available when grouping of like sections may become possible. That would tend to improve the reliability of estimates since well-defined downstream relations require relatively homogeneous controlling conditions. This paper and its companion provide merely an initial basis for estimating streamflow characteristics at ungauged sites. There is a growing awareness of the valuable role that hydraulic geometry can play in a wide variety of river engineering and management activities (Ferguson 1986).

ACKNOWLEDGEMENTS

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(accepted 15 September 1986)

SOURCES OF SHORE SEDIMENT ON THE NORTH COAST OF TASMANIA

by J.L. Davies and J.P. Hudson

(with five tables and eight text-figures)

DAVIES, J.L. & HUDSON, J.P., 1987 (30:vi): Sources of shore sediment on the north coast of Tasmania. *Pap. Proc. R. Soc. Tasm.*, 121: 137-151. ISSN 0080-4703. School of Earth Sciences, Macquarie University, Sydney, N.S.W.; and Coastal Studies Unit, Department of Geography, University of Sydney, Sydney, N.S.W.

Following a conclusion that beach sands on the north coast of Tasmania have been subjected to little longshore translocation, an attempt is made to establish their immediate provenance by examining a range of sedimentological characters. It is concluded that most of the sand body was immediately derived from the shelf at and after the postglacial marine transgression. Almost all of the remainder was supplied in the last 6000 years by erosion of coastal bedrock or accession of biogenic carbonate, with little or no contribution from the rivers.
Key Words: Sediment source, shoreline sediment, northern Tasmania.

INTRODUCTION

In a report to be published elsewhere, Davies & Hudson (in press) conclude that the north coast of Tasmania can be divided into three segments (fig. 1), each with a distinctive hinterland lithology, nearshore sediment and morphology. The strong correlation between the characteristics of hinterland and shore within each of the three segments indicates that beach sediments are autochthonous and there has been little if any longshore transport. An unresolved question which is addressed here concerns the extent to which shore sediments in each segment have been supplied most recently from the shelf or from the hinterland and in particular the extent to which rivers have supplied material in Holocene times.

Use of natural tracers to help answer the question of onshore or offshore provenance is made more difficult by the way in which the predominant geological grain everywhere runs at a high angle to the coast. Thus lithology changes along the coast in a manner which facilitates determination of degrees of longshore movement but makes distinction between river, coastal and offshore sources much less easy. At any point on the coast the lithology of catchments, cliffs and offshore outcrops is likely to be the same. In this paper an attempt is made to tackle the question of source by examining the details of sediment variation along the coast and relating these as far as possible to river mouths and coastal outcrops.

THREE COASTAL SEGMENTS

The western segment from Robbins Island to Table Cape is largely backed by arenaceous sedimentary and metamorphic rocks of Precambrian to Cambrian age. However there are outcrops of Tertiary basalt in the river catchments and on the coast at Circular Head. The shore sediments are highly quartzose with little carbonate and very small amounts of ancillary minerals. Of the heavy minerals present, tourmaline, anatase and andalusite are typical components. Prograded, ridged, barrier beaches form an apron occupying most of the shoreline, and estuaries are well filled with marine sand, indicating an abundant sediment accumulation, at least in the mid-Holocene. Levels of wind and wave energy in this segment are particularly low.

A central segment from Table Cape to Point Sorell has a hinterland with extensive sheets of Tertiary basalt, which commonly intersect the coast and crop out offshore. A quartz-deficient hinterland is paralleled by quartz-deficient shore sediments, where carbonate levels are high and rock fragments abundant. Titanaugite and kaersutite are characteristic heavy minerals. Beaches have only small foredunes at the rear and commonly there are pebble ridges at high tide mark, the pebbles originating from fluvioglacial outwash of the bigger rivers in the Pleistocene. Estuaries remain largely unfilled and the coastal sediments are also limited offshore by extensive submarine rock outcrops. This is clearly a segment where sand supply has continued to be meagre and where, in

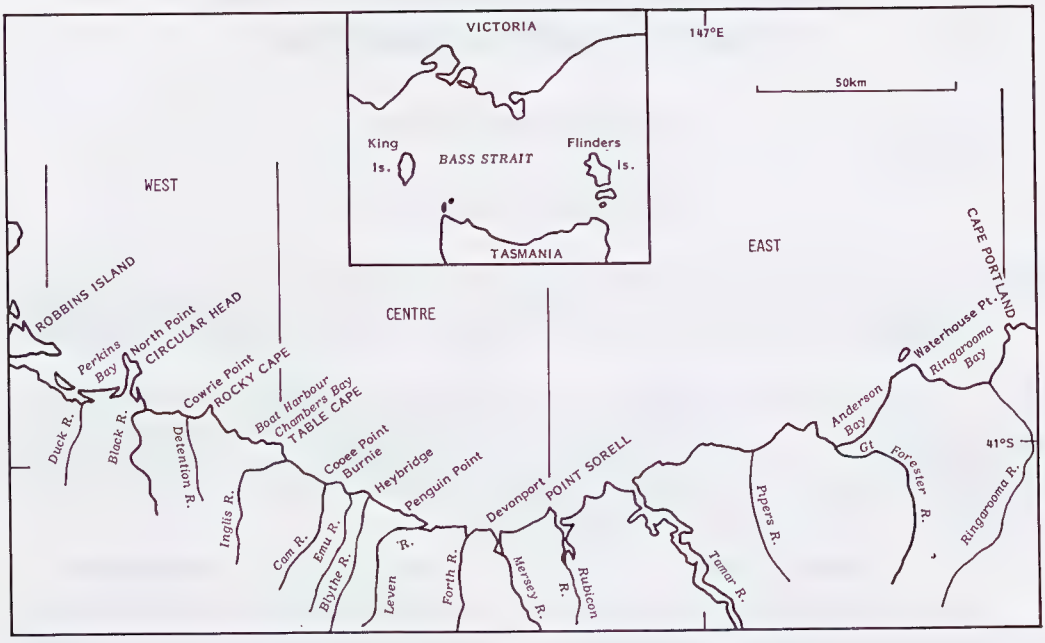

FIG.1 — Location of places and the three coastal segments mentioned in the text.

contrast to the other two segments, coastal outline has been controlled by bedrock rather than by wave forces.

The eastern segment from Point Sorell to Cape Portland is longer than the other two, with higher levels of wind and wave energy. Although there are small outcrops of Tertiary basalt and Jurassic dolerite on the shore, the hinterland is dominated lithologically by Devonian granitic rocks and by Siluro-Devonian sedimentary rocks which are commonly quartzwackes. In consequence shore sediments are rich in quartz and show a markedly higher feldspar content than in the other two segments. Hornblendes and garnets are especially abundant among the heavy minerals present. Beaches are extensive and are offset to the main coastal trend so as to face the most important waves coming from the northwest. They are backed by large transgressive dune systems apparently related to the much greater sand-moving potential of the strongly unidirectional onshore winds in this segment. Estuaries are filled with marine sand and in total there is every evidence of an abundance of shore sediment.

Taken as a whole the north coast of Tasmania, which is about 300 km long, is one of low wave energy. It faces the comparatively sheltered waters of Bass Strait and is shielded from open ocean swell. Important waves are generated by winds in Bass Strait blowing mainly from the northwest. Mean significant wave height falls from about 0.5 m in the eastern segment to about 0.3 m in the west, in contrast to the open ocean coast of New South Wales where the mean is about 1.5 m.

SEDIMENT SOURCES

The three potential sources of shore sediment in northern Tasmania are onshore transport from the shelf (referred to here as "marine"), erosion of the present shore ("coastal") and supply by rivers ("fluvial").

From experience elsewhere in southeastern Australia and indeed most of the world, the bulk of marine sand is likely to have been emplaced at and for varying times after the end of the mid-Recent sea-level rise. In southeastern Australia this is the period from about 6 500 to about 3 500 b.p. (Thom *et al.* 1981a). In northern Tasmania there is direct evidence from radiocarbon dating that the barrier systems of the western coastal segment were emplaced at this time (Thom *et al.* 1981b) and every

probability that much of the sediment caught up in the transgressive dunes of the eastern segment had a similar origin. This first major accession of sand from the shelf effectively appears to have ceased by about 3 000 b.p., but much smaller quantities of marine sand in the form of biogenic carbonate have continued to come ashore to the present day.

On a world scale, coastal erosion is usually considered to produce a very small proportion of shore sands except where erodable quartzose rocks occur (e.g. Inman 1960). Ordinarily, fluvial sediments are much more important. However research in southeastern Australia and elsewhere has demonstrated that, except on deltaic coasts, most fluvial supply occurred in the past, probably during low sea levels in the Pleistocene. Relatively little is occurring in the Holocene when most river sands have been trapped in estuaries (see Roy & Thom 1981, for instance, for New South Wales).

A distinction between the petrology of marine and fluvial sands has been made and utilised by a number of authors (e.g. Roy & Crawford 1977, Roy *et al.* 1980, in New South Wales). Because they have been reworked by waves over relatively long periods, marine sands are considered likely to be more rounded, better sorted and have a smaller proportion of less stable grains such as feldspars and rock fragments. Conversely they will have a proportion of carbonate, which is effectively missing in the rivers. Marine sands are also considered by some to be more likely to be iron stained. This has been attributed to subaerial weathering at earlier low sea levels (e.g. Emery 1965) but there are good reasons to believe that staining may occur contemporaneously in submarine conditions (Roy 1983) and the question is returned to in a later section. Sediments derived from marine erosion of bedrock outcrops on the coast are likely to be akin to fluvial sands in appearance — more angular, less well sorted, more lithic, carbonate-free and possibly not stained by iron.

In a situation of close to zero longshore transport, such as is found on the Tasmanian north coast, an assessment of the relative importance of the three sources — marine, fluvial and coastal — may be attempted by examining sediment characteristics along the coast to see whether there is any discernible correlation with river mouths and the lithology of bedrock shores. Characteristics considered in the following sections are carbonate content, sand size and sorting, quartz roundness, iron staining of quartz and carbonate, and mineralogy.

The data are derived from 165 beach samples taken to a depth of 100 mm from the mid-swash point with tidal range at springs varying from 1.8 to 3.3 m. Every beach is represented at least once, the longer ones many times. Also considered for comparison are 32 river samples in which sufficient sand for analysis was recovered, and 75 samples from the inner shelf beyond the nearshore zone.

CARBONATE CONTENT

There appear to be three probable reasons why there might be a connection between river mouths and low carbonate content in neighbouring beach sands. First, it may result directly from recent sand supply by the river itself so that marine or estuarine carbonate is diluted. Second, it may result from recycling of older leached coastal sands in the embayment associated with the river mouth, since sediments from previous depositional phases are often retained in such locations. Third, it may be a consequence of enhanced carbonate production on rocky offshore substrates between river mouths. It is extremely likely that at least echinoderms and bryozoans are more productive in these areas than in those adjacent to estuaries. The three factors are not mutually exclusive and weight should be given to all three when interpreting variations in the carbonate content of beach sands.

Figure 2 shows carbonate distribution in beach sands as measured by acid digestion. It also shows a breakdown between grains recognised as molluscan in origin and those recognised as non-molluscan — mainly echinoid, foraminiferoid and bryozoan. Unrecognisable grains have been included with the molluscan total in figure 2 since they were thought most likely to have had such an origin, but this means that the non-molluscan proportion has been artificially depressed by some variable and unknown amount. It should also be borne in mind that sample variability makes it unwise to read too much into the smaller inequalities in figure 2.

With these reservations we believe that some broad conclusions can be drawn, best considered perhaps in terms of the three coastal segments described earlier and indicated in figure 2. The sands of the western segment have low ambient levels of carbonate which occur throughout the major embayments and are unrelated to the estuaries of individual rivers. The low levels are almost certainly a result of the mass of the sand having been recycled from Pleistocene barrier systems from which carbonate had already been leached. The remains of such systems occupy most of the lowland through which flows the Duck River, outcrop in Duck Bay and at low sea levels in

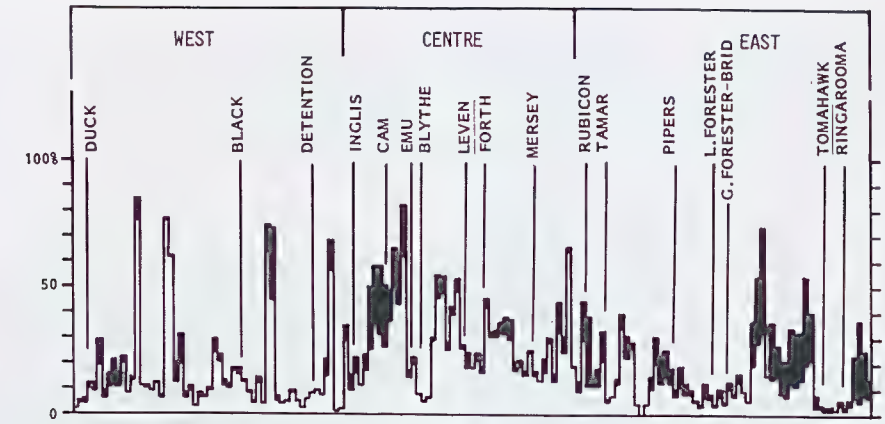

FIG.2 — Carbonate particles as a percentage of total beach sand. The identified non-molluscan content is shown in black.

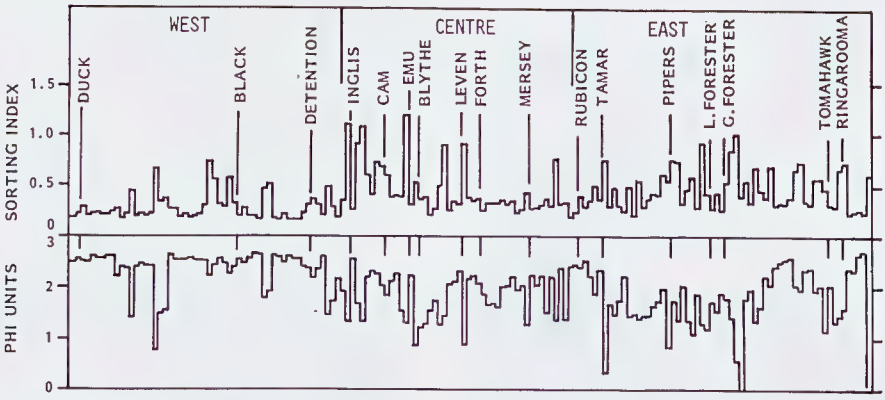

FIG.3 — Sorting measured by the Folk and Ward sorting index (above) and mean particle size in phi units (below) for total beach sand.

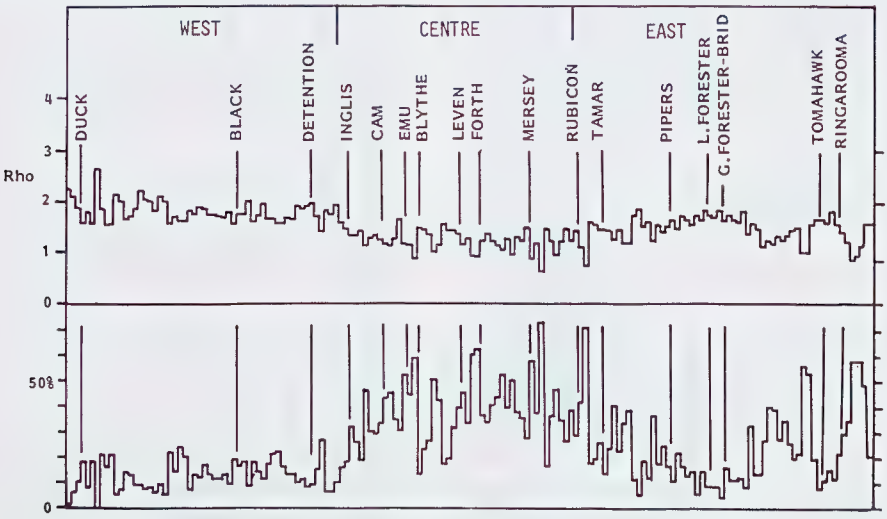

FIG.4 — Mean roundness in rho values for 2.0-2.5 phi quartz fraction (above) and percentage of 2.0-2.5 phi quartz fraction in the very angular (rho <2) class (below).

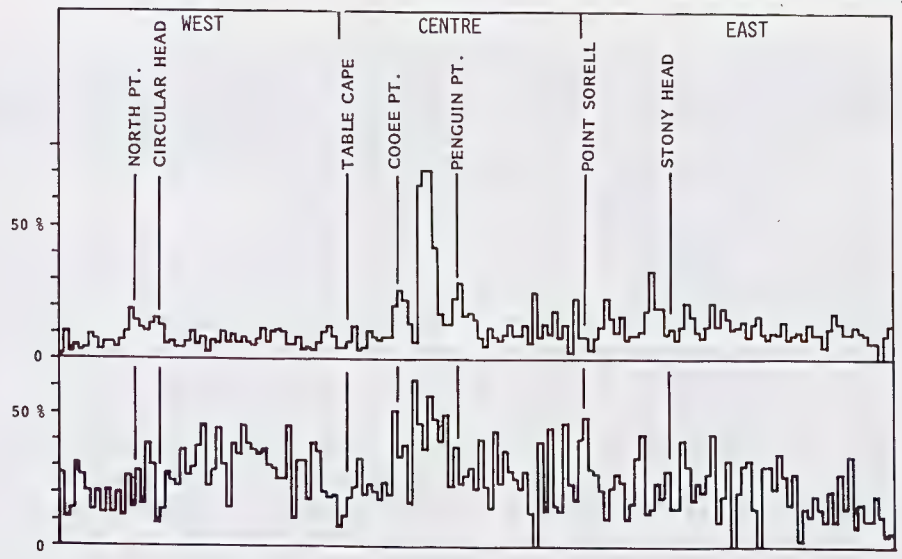

FIG.5 — Percentage of particles iron-stained in 2.0-2.5 phi quartz fraction (above) and in total carbonate fraction (below).

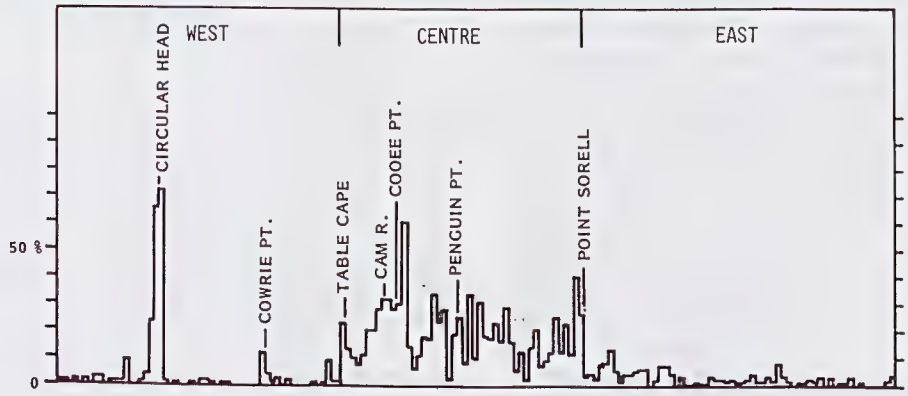

FIG.6 — Distribution in beaches of rock fragments as a percentage of rock fragments plus quartz.

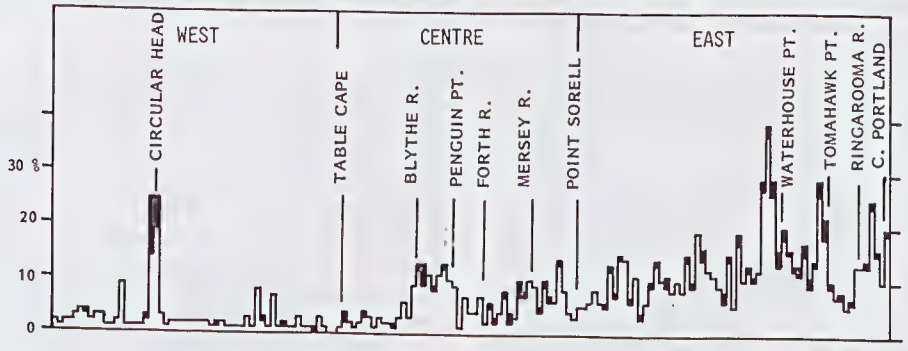

FIG.7 — Distribution in beaches of feldspars as a percentage of feldspars plus quartz. Plagioclase is shown in black.

glacial stages would have extended further north into what is now Perkins Bay. The four spectacular peaks on the graph represent small pocket beaches on headlands at North Point, Circular Head, Cowrie Point and Rocky Cape. It seems probable that little quartz was lodged in these isolated locations at the time of the postglacial marine transgression and locally produced carbonate has been the only major subsequent source of sand.

The central coastal segment is that in which the percentage carbonate content is consistently highest, reflecting its deficiency in terrestrial sediments. The rivers have high modern discharges, particularly the Forth and Mersey, but drain extensive areas of basalt and carry predominantly suspended loads. The carbonate curve in figure 2 appears depressed around the estuaries of the Inglis, Leven, Forth and Mersey and more strikingly depressed around those of the Emu and Blythe. It is worth noting that the coast around the Emu and Blythe has been markedly polluted during the last half century by effluent from factories at Burnie and Heybridge; but until we know more about rates of carbonate turnover the question of whether this has had a measurable impact remains open. On the other hand, the Blythe and Emu are unusual for central segment rivers in having significant areas of granite in their catchments — about 16% of the Emu catchment and about 40% of the Blythe — and this may have enhanced quartz supply locally in the Holocene. Sediments near the mouth of the Cam show only a slight decrease in carbonate content, which is not surprising since the Cam has the highest proportion of basalt (about 66%) in its catchment of all the major streams on this coast.

In the eastern coastal segment the proportion of carbonate in beach sands is intermediate between that in the other two. The most marked features of the curve are the reduced levels in Anderson and Ringarooma Bays. However, as in the western segment, the reductions are not related to the mouths of particular rivers. Here also there has been a degree of recycling of Pleistocene and older Holocene sands in the embayments, so that low carbonate levels may well be due to incorporation of more ancient leached dune and beach sediments. What is termed the Tamar River is in reality the submerged section of a tectonic trough into which the North and South Esk Rivers have brought great quantities of mud from predominantly dolerite catchments in the interior of Tasmania. Its mouth is occupied by a large subaqueous tidal delta of marine sand and there is no apparent likelihood of fluvial sands having been moved through this system to the coast in the Holocene. Indeed Greens Beach, which is the only marine beach actually within the Tamar mouth, shows up as a peak on the carbonate curve in figure 2. The Rubicon estuary also occupies a tectonic depression, but one which is shallower and filled with marine sand: it does not appear to be associated with a local reduction in beach carbonate.

In summary we believe that recycling of older leached coastal sands is probably responsible for the lower levels of carbonate in Perkins and Sawyer Bays in the west and in Anderson and Ringarooma Bays in the east. It is only in the centre, where there has been much less retention of Pleistocene sand, that there is a clear association between carbonate reduction and the mouths of individual rivers. On first consideration this may be due to recent fluvial sand supply, but it is evident from figure 2 that the interfluvial carbonate peaks owe much to a bigger non-molluscan component here than near the estuaries and this suggests that the differential productivity factor may have had at least some effect.

SAND SIZE AND SORTING

Cumulative curves of particle size of the sand fraction were obtained by settling tube and this was the total sample in all but a few cases. Statistical dispersion of grain size for each sample as measured by the Folk and Ward sorting coefficient is shown in figure 3, which also displays mean grain size in phi units. Expectably there is a good correlation between sorting and grain size, with coarser sands being more poorly sorted. A visual impression of this can be obtained from figure 3, where the curve for sorting approaches a mirror image of the residual of the mean phi curve. A statistical indication can be gained by simple regression which gives, with 165 pairs, a highly significant correlation coefficient of -0.699 for sorting against mean grain size.

The sands of the western segment are particularly well sorted: mean sorting coefficient is 0.28 compared with 0.46 in each of the other two segments. They are also markedly finer: mean phi is 2.35 compared with 1.88 in the centre and 1.76 in the east. Uniformity of sand in the western barrier embayments is broken by headland beaches where coarser, more poorly sorted sand contains more numerous carbonate particles and rock fragments. This coincidence between size parameters and mineralogy is common elsewhere along the coast.

In table 1 mean grain size and sorting values for the coastal samples are compared with those from rivers and from the inner shelf. Here and also

TABLE 1

Mean grain size and sorting (Folk and Ward sorting coefficient) of river, shore and shelf samples. Standard deviations in brackets.

		Number of samples	Mean phi	Mean sorting
WEST	river	6	1.48(0.63)	0.54(0.20)
	shore	56	2.35(0.38)	0.28(0.13)
	shelf	23	2.24(0.80)	0.35(0.12)
CENTRE	river	14	1.33(0.80)	0.60(0.14)
	shore	48	1.85(0.43)	0.46(0.25)
	shelf	27	2.05(0.92)	0.46(0.15)
EAST	river	17	1.58(0.70)	0.69(0.19)
	shore	61	1.76(0.60)	0.46(0.19)
	shelf	25	2.58(0.38)	0.33(0.14)

TABLE 2

Carbonate content, quartz staining and roundness of river, shore and shelf samples. Standard deviations in brackets.

		Number of samples	Percent carbonate content	2.0-2.5 phi quartz	
				% iron staining	quartz mean rho
WEST	river	7	0(0)	27(17)	2.5(0.2)
	shore	56	18(21)	7(4)	2.8(0.2)
	shelf	23	26(21)	7(4)	2.8(0.3)
CENTRE	river	14	1(1)	39(17)	2.3(0.1)
	shore	48	33(18)	16(16)	2.2(0.2)
	shelf	25	33(14)	26(22)	2.3(0.2)
EAST	river	17	1(1)	22(16)	2.4(0.3)
	shore	61	19(15)	12(5)	2.5(0.3)
	shelf	25	12(7)	11(5)	2.4(0.2)

TABLE 3

Percentage of quartz and carbonate grains which are iron stained. Standard deviations in brackets.

	West	Centre	East
Number of samples	56	48	61
% 2.0-2.5 phi quartz iron stained	7(4)	16(16)	12(5)
% 1.0-1.5 phi quartz iron stained	11(6)	26(16)	17(8)
% quartz in total sand	78(22)	53(17)	68(16)
% carbonate iron stained	26(10)	29(13)	20(11)
% carbonate in total sand	18(20)	33(18)	19(15)

in table 2 the river samples were necessarily restricted to those which contained enough sand for analysis, while the shelf samples come from the innermost shelf outside the nearshore zone.

The mean values show a contrast between coarser, more poorly sorted fluvial sands and finer, better sorted shore and shelf sands. However, bearing in mind the likely limitations placed on the curve by the sampling intensity, there seems no consistent suggestion in figure 3 of poorly sorted, coarser beach sands near river mouths due to fluvial sand input. Minor peaks of mean particle size and poor sorting which occur near some estuaries are based on only one sample, reflecting very local conditions and may be misleading. For instance, the sample immediately west of the Mersey River mouth comes from a small beach, pocketed in basalt, with a large proportion of rock fragments and little connection with the river itself. The only peaks in the curves based on several samples appearing near estuaries are at the Cam and Pipers Rivers, but many more peaks occur away from rivers than are near them. In sum we do not find the distribution of particle size or sorting helpful in illuminating the possibility of recent sand supply by rivers.

QUARTZ ROUNDNESS

Roundness of the 2.0-2.5 phi quartz fraction was determined by visual comparison on the Powers scale. This size class was chosen because it was the only half-phi interval common to all the samples. Determinations were also made for the 1.0-1.5 phi component although this reduced by five the total of samples available. Figure 4 shows mean roundness for 2.0-2.5 phi quartz, as measured by the rho scale of Folk (1955), a logarithmic version of the Powers verbal classes. Results for the 1.0-1.5 fraction are very similar. The means for almost all samples fall between 2 and 3 rho, or in the subangular class. Since a large amount of operator judgement is involved in the analysis, it is relevant to note that independent analysis of 15% of the samples by a second operator gave substantially the same result.

Table 2, compiled on the same basis as table 1, suggests that there is no significant difference in northern Tasmania between fluvial and marine sands in degree of roundness. The use of grain roundness as evidence of modern river supply is thus made especially difficult. However the general distribution patterns of mean rho values shown in figure 4 display broad differences in degree of rounding of beach sands coinciding closely with the three coastal segments. Quartz sands are least angular in the west, most angular in the centre and become less angular again in the east. Mean figures for 2.0-2.5 phi quartz are 2.80 rho in the west, 2.24 in the centre and 2.45 in the east. For the 1.0-1.5 phi component the corresponding figures are 2.63, 2.14 and 2.60. The same general patterns are evident in the other histogram in figure 4, which gives percentages of grains in the angular and very angular classes (rho values of less than 2.00).

It was suggested earlier that reduced carbonate levels in the large embayments of the western and eastern coastal segments can be associated with the reworking of older sediments and it is evident from figure 4 that these embayments are also characterised by reduced levels of quartz angularity. This is consistent with the notion of repeated recycling in the embayments with recurring episodes of aeolian action, since wind transport is generally regarded as the most effective process in rounding sand grains and selectively concentrating those already rounded (Kuenen 1960, Mazzullo *et al.* 1986). An important consideration is that, in the west and east, there always appears to have been a much greater quantity of sand above high water mark available for reworking by winds exceeding the appropriate threshold velocity.

The central segment stands out as that with a high proportion of angular quartz grains, though it seems impossible to associate angular quartz with particular rivers, other than perhaps the Forth (fig. 4). If the greater rounding of grains in the west and east owes something to aeolian influence during recycling phases, it may be that the greater overall angularity in the centre is due to the paucity of dunes and much smaller potential for wind action now and in the past.

IRON STAINING

The percentage of grains judged by eye to exhibit staining by iron oxides was determined for quartz in the 2.0-2.5 phi fraction. The 1.0-1.5 phi fraction was also examined, although again this meant five samples were unavailable and results were closely parallel. The data for 2.0-2.5 phi quartz are portrayed in figure 5, which also purports to show the distribution of iron-stained carbonate grains. Difficulty was experienced in judging by eye the degree of staining of carbonate because naturally pigmented grains could not always be separated with confidence. The technique used eventually was to make an initial assessment of the apparently stained grains in a sample and then place the

TABLE 4

Quartz, feldspar and rock fragments as percentages of river, shore and shelf samples. Standard deviations in brackets.

		n	Quartz	Feldspar	RF's
WEST	river	5	80(12)	2(1)	17(10)
	shore	56	94(13)	2(2)	4(12)
	shelf	23	91(11)	2(2)	7(11)
CENTRE	river	11	61(17)	7(6)	31(18)
	shore	48	77(10)	5(3)	18(11)
	shelf	27	71(18)	3(2)	26(19)
EAST	river	16	86(7)	8(5)	5(4)
	shore	61	85(7)	13(7)	2(2)
	shelf	25	85(5)	7(3)	8(5)

TABLE 5

Rock fragments in sands near the Cam River.

	Sample number	% fragments in light minerals	% clastics in rock fragments
River	1246	45	19
Shore	230	31	66
	212	32	69
	231	33	77
	232	33	84
	234	57	77
Shelf	C4	72	63
	C5	59	87
	C6	54	91

sample in 150 ml of water at 70-80° C to which 2-3 g of sodium dithionite was added. The water was kept at starting temperature and agitated for 5 minutes; then allowed to cool. The sample was rinsed, oven dried and the percentage of apparently stained grains was recalculated. The difference between the first assessment and the second assessment was taken to represent the amount of discolouration actually due to iron staining. The double assessment has the disadvantage of introducing a second sampling error into the procedure because different subsamples are used for counting on the two occasions. This is reflected in the histogram for carbonate in figure 5 which shows even more random "noise" than the histogram for quartz, but we have no reason to doubt that the general levels shown are indicative of reality.

Table 3 confirms the visual impression given by the histograms that carbonate grains were found to be more iron-stained than quartz grains and that coarser quartz is more stained than finer quartz. This latter difference may be explicable at least in part by suggesting that the finer quartz grains have suffered greater abrasion and rounding, but Judd *et al.* (1970) concluded that this was not a supportable explanation for a similar situation in eastern U.S.A. In any event the differences help to pose the question of the origin and significance of the iron staining.

Table 2 gives values for iron staining of the 2.0-2.5 phi quartz fraction in rivers, on shore and on the inner shelf on a basis already described. It shows river sands to be more stained than both shore and shelf sands in all three segments. The differences are statistically significant at better than the 95% level in all cases except between river and shelf sands in the centre where the level of confidence falls to about 93%. There is no support

for the idea of rivers supplying relatively clean quartz to the marine environment where it becomes iron-stained by subaerial processes at low sea level. The suggestion in table 2 is rather that the rivers have supplied stained quartz at low sea levels; that this has been piled into dunes which have been leached and that it has then been recycled into the beach deposits at the present sea level. Such a scenario would help to explain why staining of shore and shelf sands is more significantly lower than that of river sands in the western and eastern coastal segments where dune building and recycling have been especially prevalent. It seems evident that the iron oxides responsible for the original staining of the river sands came primarily from breakdown products of the basalt. These occur in nearly all stream catchments but particularly in the centre, which accounts for the high level of iron staining in this coastal segment.

That this is not the complete explanation is shown by the fact that percentage iron staining of carbonate particles is consistently higher than that for quartz and the carbonate of course is not supplied from rivers. Iron staining of carbonate must either have taken place in the marine environment or have occurred on the shelf in subaerial conditions at low sea level. The possibility of the second explanation being correct seems remote, because carbonate leaches readily from subaerial sands in Tasmanian conditions and is scarce or absent in the Pleistocene dunes of the western and eastern segments. Even in the oldest of the Holocene beach ridges, dating presumably from about 6000 b.p., most carbonate has been leached. The conclusion seems inescapable that iron staining of marine carbonate particles is a modern process and we note that Roy (1983) obtained a date of 1 500 ± 135 C^{14} years b.p. for iron stained shell off the Sydney coast.

Although some quartz grains have been iron-stained in the modern marine environment the evidence points to carbonate grains being distinctly more susceptible to staining and this is what would be expected on theoretical grounds. Professor P.B. Hostetler, School of Earth Sciences, Macquarie University, has pointed out to us that in a laminar flow environment, where a diffusion gradient for soluble iron is readily visualised, ferric hydroxide is more apt to precipitate from aqueous fluid immediately surrounding a grain of calcium carbonate than from the fluid around a quartz particle. This is because a solution reaction between the carbonate grain and its surrounding fluid will cause a local increase in hydroxide which in turn will favour precipitation of ferric hydroxide from the sea. No such hydroxide enrichment occurs around quartz grains in a similar situation.

It appears that iron stained quartz has been supplied by rivers at Pleistocene low sea levels and only to a small extent by processes operating on the Holocene sea bed. Leached quartz coming from the erosion of old shore sediments has served to reduce the ultimate percentage of grains observed to be stained by iron. Iron stained carbonate on the other hand has resulted from the more efficient submarine absorption of iron in the last 6000 years.

Returning to the distribution patterns in figure 5, it is necessary to note that the most striking peak in both curves is man-made. This is associated with effluent from the titanium dioxide factory at Heybridge which locally causes staining of bedrock and sediments with hydrous ferric oxide. The curves suggest that the effect may extend from Cooee Point to Penguin Point and may be more widespread on carbonate sands than on quartz sands. They also confirm that both quartz and carbonate particles are stained in the contemporary marine environment where favourable conditions are present.

From the residual natural curves it is not possible to determine any clear association of staining peaks or depressions with river mouths. The only apparent correlations in detail are between increased staining and areas where basalt occurs to landward and there are unusual numbers of volcanic rock fragments and iron ore minerals in the beach sands. The generally high values throughout the central segment and the peaks which occur at North Point-Circular Head and west of Stony Head provide examples of such correlations.

LITHIC FRAGMENTS

Sand particles that have not yet broken down into their constituent mineral grains are usually considered unstable in high energy environments such as ocean beaches. Their presence in beach sediments may therefore be indicative of recent supply. Figure 6 shows the distribution of rock fragments in northern Tasmanian beaches expressed as a percentage of rock fragments plus quartz, and in table 4 the mean percentages for beaches are compared with those for available river and shelf samples in the three coastal segments. It will be seen that lithic fragments are particularly prevalent in the central coastal segment, where they appear to originate from the Tertiary basalts and the Precambrian Burnie Formation — a series of strongly folded, sheared and foliated micaceous quartz-wackes.

Table 4 suggests that, on the whole, rock fragments are less common in beaches than in rivers or on the contiguous shelf and this difference is statistically significant in all cases at better than 95%. Given the high proportion of rock fragments in river sands it is notable that figure 6 gives no indication (except perhaps for the River Cam) of increased lithic content in beaches near estuaries. The most prominent isolated peaks are around headlands, notably Circular Head, Table Cape, Cowrie Point and Cooee Point. Between Penguin Point and Point Sorell basalt occurs regularly in cliffs, on shore platforms and offshore, and lithic fragments are being supplied to beaches from these sources all along this stretch of coast.

The peak in the figure 6 histogram around the mouth of the Cam calls for more detailed examination. About 66% of the catchment of this river is floored by basalt and about 17% by the Precambrian Burnie Formation. The basalt covers the upper part of the catchment, with the Precambrian rocks cropping out in the lower parts of the main valley close to the sea. The coast on either side of the Cam estuary for at least 15 km is formed in the Precambrian, which is also found offshore. There are only three very minor coastal occurrences of basalt. A sediment sample from the river bed 1 km above tidal limit contained 55% silt and clay, but among the light minerals separated from the sand fraction 45% were found to be rock fragments. In table 5 this sample is compared with beach samples around the mouth of the river and with three samples from the shelf 0.7, 1.7 and 2.7 km off Cooee Point. It will be seen that, although the river sample contains a higher proportion of rock fragments than all but one of the beach samples, the proportion of clastics in the rock fragments is far higher in the beaches and on the shelf than in the river, indicating that the major supply is from the Precambrian rocks on the coast and offshore.

Lithic fragments are an important volumetric constituent of beach sands only in the central coastal segment, but here they average about 18% of inorganic sand and about 12% of the total shore sediment. Their probably short life span suggests that they have been supplied mainly since the postglacial marine transgression, but from erosion of coastal bedrock and not from rivers.

FELDSPARS

In New South Wales the occurrence of feldspar concentrations in beach sands has been used as evidence for recent sand supply by rivers (Bird 1967, Roy & Crawford 1977). The distribution of feldspars in northern Tasmanian beach sands is shown in figure 7, where abundance is expressed as a percentage of feldspar plus quartz. The proportion of constituent plagioclase is also shown. The overall distribution pattern demonstrates a strong connection between feldspathic sands and granitic rocks, with particularly large feldspar concentrations in the eastern coastal segment where granites and granodiorites occur in catchments and in places on the coast. On average, feldspars contribute about 13% of inorganic beach sand in this segment and about 11% of the total sand body.

The dolerites and basalts are also potentially large sources of feldspar, but overwhelmingly of sodic feldspars. The fact that we found only relatively small amounts of sodic feldspar supports the general view that it has a relatively short life in the detrital state, even though this may depend on the nature of the local weathering environment (Todd 1968). Plagioclase appears to be common as a component of volcanic rock fragments but uncommon in the form of independent sand grains. Alkali feldspars are only a minor constituent of the dolerites and are even scarcer in most of the basalts (Edwards 1942, 1949), but may be derived from these rocks in significant amounts where there is a relatively large source.

The histogram in figure 7 shows a detailed relationship of feldspar peaks to headlands rather than to estuaries. A marked peak occurs around Circular Head where the basalt has been observed by Edwards (1941) to contain abnormally high quantities of alkali feldspar and the plagioclase content of beach sands is also exceptionally great. Other prominent peaks are associated with Waterhouse Point and Tomahawk Point, where dolerite and granite outcrop extensively and with Cape Portland-Petal Point, where dolerites and appinites form the shore (Jennings & Sutherland 1969). The only indication of a river source is the rise in feldspar content east of the mouth of the Blythe which has 40% of its catchment floored by granitic rocks.

The evidence indicates that, particularly in the east, weathering and erosion of coastal bedrock has been a source of feldspar sand since the postglacial marine transgression and that the River Blythe may also have been a source. The data in table 4, suggesting that the highest proportion of feldspar in the east occurs on the shore but in the centre occurs in the rivers, are in sympathy with this conclusion. However it is necessary to exercise some caution regarding the time of supply. Alkali feldspar grains do not appear particularly unstable in marine conditions and are known to have

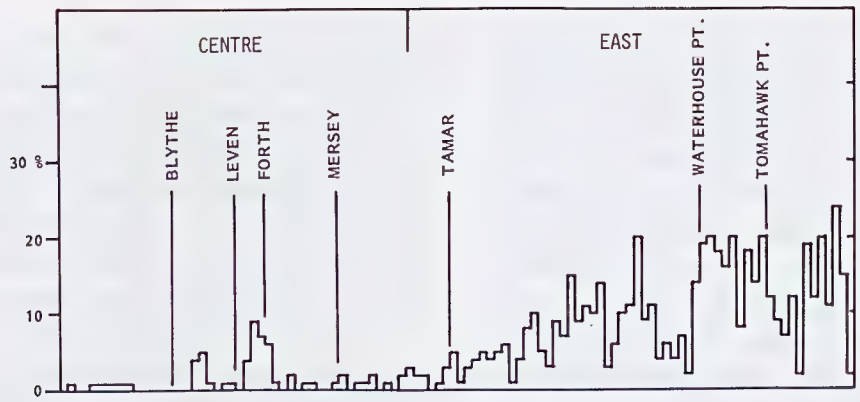

FIG.8 — Hornblende as a percentage of heavy minerals in beach sands in the central and eastern segments.

survived on the shelf and in the beaches of south-eastern U.S.A. through at least the Late Pleistocene (Field & Pilkey 1969). On a coast where longshore transport has been severely limited, the possibility that particular concentrations may have had a pre-Holocene origin can not be ruled out.

HEAVY MINERALS

The general distribution of heavy minerals has been outlined elsewhere (Davies & Hudson in press). Although they rarely make up more than 1% of beach sand in northern Tasmania, their distribution may be relevant in so far as those with a hydraulic equivalence closer to quartz may serve as natural tracers. The least stable minerals are those most likely to be indicative of recent supply and, as in the case of rock fragments and feldspars, observable relationships are with headlands and not estuaries. Thus, although olivine is infrequent in beach sands, an unusually large amount was found adjacent to North Point, where it must have emanated recently from weathered basalt at the shore. Of the pyroxenes, titanaugite is especially common because of its considerable representation in the basalt, but its detrital distribution in the beaches is strongly related to coastal basaltic outcrops such as Circular Head, Table Cape and Penguin Point (see discussion and fig. 5 in Davies & Hudson in press). A strong concentration of the titaniferous amphibole, kaersutite, was found near Burnie and there is probably a source in the small basalt outcrop close to the beaches where it is very plentiful.

The only evidence for possible river supply is provided by a hornblende concentration in beaches near the mouth of the Forth. Figure 8 shows that hornblendes are largely confined to the eastern coastal segment where granitic rocks are widespread. They are particularly prevalent around Waterhouse Point where granites crop out on the shore. However there is a distinct hornblende peak around the mouth of the River Forth, which has some granite and amphibolite in its catchment and where there seems no likely coastal source for abnormal amounts of hornblende. Recent work by one of us (Hudson 1986) has shown that hornblendes have survived one or more cycles of sea level change on the New South Wales coast and this casts some doubt on the time of supply.

DISCUSSION

Although much of the evidence is equivocal and difficult of precise interpretation in isolation, some conclusions can be reached by drawing different strands together. In the western coastal segment there is no evidence of Holocene river supply. Beach sands here show great internal homogeneity broken only by the local influence of the basalt at Circular Head which has supplied feldspars, rock fragments and pyroxenes in small quantities to contiguous shores. It is evident that the finer, better sorted, less angular, highly quartzose sands which make up almost all the beach sediments here result from the recycling of older shore bodies at different times in the Quaternary, most recently at and immediately after the postglacial marine transgression. Their ultimate source appears to have been in the Precambrian rocks of the Black and Detention catchments and the Rocky Cape Range.

In the eastern coastal segment the picture is less simple but again there is no compelling indication of Holocene river supply. Quartz sand is actually less rather than more angular in Anderson and Ringarooma Bays and around the mouths of the Great Forester-Brid and Ringarooma Rivers than it is in interfluvial sections, suggesting that here, as in the west, the bulk of the sand has been recycled from old dunes and beaches. The reduced carbonate levels in sands around these rivers and in their contiguous embayments are also best explained in terms of quartz being added from this source. The Ringarooma, which has much the highest discharge of rivers in the east, is at present cutting into older transgressive dunes above its estuary and carrying sand back to the shore. To this mass of recycled quartz, coastal erosion of weathered shore outcrops of dolerite and granite has added small amounts of feldspathic sand in Holocene times.

In total the evidence from the eastern segment points again to sediments having been emplaced from seaward by the postglacial marine transgression, having been deflated and recycled to varying extents and supplemented in minor degree by erosion of weathered bedrock on the present shore. However the ultimate (Pleistocene) source of the bulk of the sand seems to have been in the granites and granodiorites of the river catchments and in the associated terrestrial sand mantles mapped as being Tertiary in age (for example Geological Survey of Tasmania, 1:250 000 series, sheet 4, 1975).

The central coastal segment contains much the biggest concentration of rivers and in particular the Forth and Mersey which, leaving aside the rivers of the Tamar system, are easily the two largest along the whole coast. Yet it also has much the smallest nearshore sand body, which very rarely contains more than 75% quartz and usually much less. Since longshore transport appears to have been absent, the scarcity of sand in general and quartz in particular must be attributed primarily to low sediment inputs and the relative scarcity of quartz in the rocks of the hinterland. Biogenic carbonate fragments and lithic particles derived mainly from weathering and erosion of coastal bedrock have made exceptionally large contributions to the beach sands. Longstanding quartz deficiency and lack of longshore translocation has also meant that the sand body emplaced from the shelf by the postglacial transgression was meagre and only a small amount of sediment has been available for transfer into the estuaries. The relative lack of infilling of estuaries in the centre can not be attributed to their having had a large initial volume. Because the rivers have been adjacent to a wide shallow shelf, there has been little downcutting during low sea-level phases by even the biggest of them — a maximum of only 15 m below present sea-level by the Mersey at Devonport for instance (Moore 1968).

The Forth and Mersey estuaries are wide, with small tidal deltas separated from upstream fluvial deltas by residual mud basins (compare Roy 1984). They appear very unlikely to be transporting bedload through to the shore. Conversely the Cam, Emu and Blythe have very narrow estuaries into which there has been hardly any incursion of marine sand and where the ratio of river discharge to tidal discharge is high for much of the time. These rivers appear *a priori* the most likely to have carried fluvial sand to the shore. The remaining estuaries are of an intermediate nature.

Against this background it is not surprising that the evidence for recent river supply to the coast is slender. The best evidence is for the Blythe and the Emu, where there is the most marked carbonate depression and a distinct feldspar peak. Both rivers have granite in their catchments and, along with the Cam, are most likely to have been suppliers judging by morphology and hydrology. The Cam has a strongly basaltic catchment and is mostly delivering mud, but it may also supply some volcanic rock fragments to augment the high proportion of lithics in the beaches derived mainly from the erosion of Precambrian bedrock. There is only a small depression in the carbonate curve opposite the Cam. The next best evidence is for the Forth, where a less specific reduction in carbonate is accompanied by a hornblende peak and perhaps more angular quartz. However the morphology of this estuary suggests that this river is very unlikely to be carrying sand to the coast at present and the hornblende peak may be inherited from the Pleistocene.

Elsewhere in the centre the only possible indication of recent sand supply by rivers is that of reduced carbonate content, for instance around the Leven, Mersey and Inglis mouths. Earlier, less detailed work suggested to one of us (Davies 1980, p.124) that this was good testimony to recent quartz infusion, but the lack of supporting evidence from other criteria used in the present enquiry suggests that the factor of varying carbonate productivity between estuaries and headlands may be more important than was originally thought. It may also be that too much of the unidentified carbonate has been allocated to the molluscan category in figure 2. On the total evidence we

conclude that the Blythe, Emu and Cam may have supplied some shore sediment since the postglacial marine transgression but there seems no convincing evidence for any other river. Such a conclusion is supported by the limited amount of shore sand in the central coastal segment and the difficulty of pointing to specific sediment accumulations which can be associated with particular points of fluvial injection. The absence of such accumulations on a coast of close to zero transport must be significant.

In summary it appears that in the central segment the postglacial marine transgression brought only a relatively small body of sand from the shelf. In the Late Holocene this has been augmented by lithic fragments produced from coastal erosion, by biogenic carbonate and possibly by injection of some sand from the Blythe, Emu and Cam Rivers.

CONCLUSION

The shore sands of northern Tasmania, like those of other southeastern Australian coasts, were derived almost entirely from the shelf at the time of the postglacial marine transgression and during subsequent periods of adjustment of the nearshore profile. They incorporated older beach and dune sands, especially in the west and east, sands which had been brought to the lower reaches of the rivers at low sea level times and coarser material weathered from bedrock outcrops, of which there are many on the shelf in the central and eastern segments. Since the transgression there have been accessions of carbonate sand, mainly around the rocky interfluvial areas, and small quantities of lithic and feldspathic sand have come from coastal erosion, principally of weathered granite, dolerite, basalt and quartzwackes. Of the rivers, the Blythe, Emu and Cam may have supplied a very small amount of sand, but, if so, this has been insignificant in terms of the total sediment body.

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CHECK-LIST OF THE TASMANIAN LIVERWORTS

by D. A. Ratkowsky

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A check-list of the Tasmanian liverworts is presented in an attempt to include all the species (282) that are presently believed to occur in Tasmania. The Lepidoziaceae is viewed as the family most in need of revision in southern Australia today.

Key Words: Tasmania, liverworts.

INTRODUCTION

It has been three score and ten years since the last major revision of the Tasmanian hepatic flora was published (Rodway 1917). Since that time, many advances have been made in our knowledge of the liverworts in this region. Nevertheless, there has been no systematic work to replace Rodway's study, although it is now widely recognised that many species in that work are synonyms, and that several other species have been discovered in the past seven decades which are absent from that work.

A valuable paper on the liverworts of the whole of Australia is the annotated list of binomials and check-list of published species by Scott & Bradshaw (1985). That study was the starting point for the present paper, as it dealt critically with all the species names that were proposed up to about 1983.

RESULTS AND DISCUSSION

The check-list of Tasmanian liverworts is presented in table 1. The arrangement of orders and families follows that of Scott & Bradshaw (1985), although the spelling of two families, Balantiopsaceae and Chaetophyllopsaceae, have been altered from their spelling in that work on the advice of Dr R. Grolle (*pers. comm.*). Within families, genera are listed in alphabetical order, as are species within a genus.

A total of 282 species appears in the list in table 1. This has to be considered to be a tentative list of the liverwort species of Tasmania, as several families, or genera within families, require revision. For the Anthocerotales, a complete revision of this order of plants in Australia needs to be undertaken. For the order Metzgeriales, the genus *Metzgeria* is the most problematic, requiring revision. In the Aneuraceae, the genus *Riccardia* undoubtedly has some further undescribed species. *Fossombronia* is an extremely difficult genus to identify to species level and the Tasmanian list of species for this genus is likely to be incomplete or erroneous. In the Pallaviciniaceae, the check-list follows the recent opinion of Dr R. Grolle (*pers. comm.*), who currently believes, based on his herbarium studies, that in the genera *Pallavicinia* and/or *Jensenia*, only *Pallavicinia rubristipa* and *P. xiphoides* actually occur in Tasmania, with all records of *Jensenia connivens* (Col.) Grolle, *J. pisicolor* (Hook. f. & Taylor) Grolle and *Pallavicinia lyelli* (Hook.) S.F. Gray from Tasmania being wrong. *Symphyogyna rhodina* has recently been rediscovered in Tasmania (collected by A.V. Ratkowsky), but study is needed to determine whether or not this species is another form of the highly polymorphic *S. podophylla*. Also, the type of *S. interrupta* needs examination.

In the order Marchantiales, a family that needs critical study is Ricciaceae. Although the genus *Riccia* in Australia was revised by Na-Thalang (1980), Tasmania was omitted from consideration. Thus, the species of *Riccia* in this check-list are preceded by a question mark and their identity must be viewed as doubtful. In Aytoniaceae, Dr R. Grolle (*pers. comm.*) asserts that *Asterella australis* (Tayl.) Verd., formerly believed to occur in Tasmania, is endemic to New Zealand.

The Jungermanniales is by far the largest order of liverworts and the one with the most pressing taxonomic problems. The situation with respect to Lepidoziaceae is serious, as there does not appear to be any hepaticologist currently working on a revision of this difficult family. The problem genera are *Bazzania*, *Kurzia* and *Telaranea*. Although *Bazzania monilinervis* is a distinctive species, *B. adnexa* and *B. involuta* may be synonyms of a single very variable species. Although *Kurzia* and *Telaranea* appear in the list with nine species each, it is likely that some of the names in each

TABLE 1

Check-list of Tasmanian liverworts.

ANTHOCEROTALES

Anthocerotaceae

Anthoceros laevis L.
Megaceros longispirus (Carringt. & Pears.) Steph.

METZGERIALES

Aneuraceae

Aneura alterniloba (Hook. f. & Tayl.) Hook. f. & Tayl.
A. rodwayi Hewson
Riccardia aequicellularis (Steph.) Hewson
R. alcicornis (Hook. f. & Tayl.) Trev.
R. bipinnatifida (Col.) Hewson
R. cochleata (Hook. f. & Tayl.) Kuntze
R. colensoi (Steph.) Martin
R. crassa (Schwaegr.) Carringt. & Pears.
R. eriocaula (Hook.) Besch. & Massal.
R. gracilis (Steph.) Schust.
R. longiflora (Steph.) Hewson
R. minima Carringt. & Pears.
R. nitida (Col.) Hodgs.
R. rupicola (Steph.) Hewson
R. wattsiana (Steph.) Hewson

Fossombroniaceae

Fossombronia intestinalis Tayl.
F. pusilla (L.) Nees

Hymenophytaceae

Hymenophyton flabellatum (Labill.) Dum. ex Trev.
H. leptopodum (Hook. f. & Tayl.) Evans

Pallaviciniaceae

Pallavicinia rubristipa Schiffn.
P. xiphoides (Hook. f. & Tayl.) Trev.
Podomitrium phyllanthus (Hook.) Mitt.
Symphyogyna interrupta Carringt. & Pears.
S. podophylla (Thunb.) Mont. & Nees
S. rhodina (Hook. f. & Tayl.) Tayl.

Metzgeriaceae

Metzgeria atrichoneura Spruce
M. australis Steph.
M. colensoi Steph.
M. conjugata Lindb.
M. decipiens (Massal.) Schiffn. & Gott.
M. densiseta Steph.
M. furcata (L.) Dum.
M. leptoneura Spruce
M. pinnata Steph.
M. saccata Mitt.

Treubiaceae

Treubia lacunosa (Col.) Prosk.
T. tasmanica Schust. & Scott

Vandiemeniaceae

Vandiemenia ratkowskiana Hewson

MARCHANTIALES

Aytoniaceae

Asterella drummondii (Hook. f. & Tayl.) Schust.
A. tasmanica (Steph.) Schust.
A. tenera (Mitt.) Schust.
Reboulia hemisphaerica (L.) Raddi

Marchantiaceae

Lunularia cruciata (L.) Dum.
Marchantia berteroana Lehm. & Lindenb.
M. foliacea Mitt.
M. polymorpha L. var. *aquatica* Nees

Targioniaceae

Targonia hypophylla L.

Ricciaceae

(?)*Riccia crassa* Steph.
(?)*R. tasmanica* Steph. ex Rodw.
(?)*R. weymouthiana* Steph. ex Rodw.
Ricciocarpos natans (L.) Corda

Monocleaceae

Monoclea forsteri Hook.

CALOBRYALES

Haplomitriaceae

Haplomitrium gibbsiae (Steph.) Schust.

JUNGERMANNIALES

Herbertaceae

Herbertus oldfieldianus (Steph.) Rodw.
Triandrophyllum subtrifidum (Hook. f. & Tayl.) Fulf. & Hatch.

Pseudolepicoleaceae

Isophyllaria attenuata (Rodw.) Hodgs.
Temnoma pulchellum (Hook.) Mitt.
T. townrowii Schust.
Trichotemnoma corrugatum (Steph.) Schust.

TABLE 1 (cont.)

Balantiopsaceae

Acroscyphella phoenicorhiza (Grolle) Kitag. & Grolle
Balantiopsis diplophylla (Hook. f. & Tayl.) Mitt.
B. tumida Berggr.
Isotachis grandis Carringt. & Pears.
I. intortifolia (Hook. f. & Tayl.) Gott.
I. nigella Herz. [syn. *Eoisotachis nigella* (Herz.) Schust.]
I. riparia Rodw.

Ptilidiaceae

Mastigophora flagellifera (Hook.) Steph.

Lepicoleaceae

Lepicolea scolopendra (Hook.) Dum. ex Trev.

Chaetophyllopsaceae

Chaetophyllopsis whiteleggei (Carringt. & Pears.) Schust.

Trichocoleaceae

Eotrichocolea polyacantha (Hook. f. & Tayl.) Schust.
Trichocolea mollissima (Hook. f. & Tayl.) Gott.
T. rigida Schust.

Lepidolaenaceae

Gackstroemia weindorferi (Herz.) Grolle
Lepidolaena brachyclada (Tayl. ex Lehm.) Trev.
L. clavigera (Hook.) Dum. ex Trev.
L. reticulata (Hook. f. & Tayl.) Trev.
L. taylorii (Gott.) Trev.

Lepidoziaceae

Acromastigum anisostomum (Lehm. & Lindenb.) Evans
A. cavifolium Schust.
A. colensoanum (Mitt.) Evans ex Reim.
A. mooreanum (Steph.) Hodgs.
Bazzania adnexa (Lehm. & Lindenb.) Trev.
B. involuta (Mont.) Trev.
B. monilinervis (Lehm. & Lindenb.) Trev.
B. novaezelandiae (Mitt.) Besch. & Massal
Hyalolepidozia longiscypha (Tayl.) Grolle
Hygrolembidium acrocladum (Berggr.) Schust.
H. australe (Steph.) Grolle
Isolembidium anomalum (Rodw.) Grolle
Kurzia cucullifolia (Steph.) Schust.
K. hippurioides (Hook. f. & Tayl.) Grolle
K. quadriseta Grolle
K. saddlensis (Besch. & Massal.) Grolle
K. setiformis (de Not.) Engel & Schust.
K. sexfida (Steph.) Grolle
K. temnomoides Schust.
K. tenax (Grev.) Grolle
K. verticillata (Carringt.) Grolle
Lepidozia concinna Col.
L. cupressina (Sw.) Lindenb.
L. glaucophylla (Hook. f. & Tayl.) Tayl.
L. laevifolia (Hook. f. & Tayl.) Tayl.
L. microphylla (Hook.) Lindenb.
L. pendulina (Hook.) Lindenb.
L. procera Mitt.
L. ulothrix (Schwaegr.) Lindenb.
Neogrollea notabilis Hodgs.
Pseudocephalozia paludicola Schust.
Psiloclada clandestina Mitt.
Telaranea capilligera (Schwaegr.) Schust.
T. centipes (Tayl. ex Gott. *et al.*) Schust.
T. gottscheana (Lindenb.) Hodgs.
T. grossiseta (Steph.) Engel & Schust.
T. herzogii (Hodgs.) Hodgs.
T. mooreana (Steph.) Schust.
T. patentissima (Hook. f. & Tayl.) Hodgs.
T. praenitens (Lehm. & Lindenb.) Hodgs.
T. tetradactyla (Hook. f. & Tayl.) Hodgs.
Zoopsis argentea (Hook. f. & Tayl.) Hook. f.
Z. leitgebiana (Carringt. & Pears.) Bastow
Z. setulosa Leitg.

Calypogeiaceae

Calypogeia sphagnicola (H. Arnell & Perss.) Warnst. & Loeske

Jungermanniaceae

Anastrophyllum schismoides (Mont.) Steph.
Andrewsianthus perigonialis (Hook. f. & Tayl.) Schust.
Chandonanthus squarrosus (Hook.) Mitt.
Cryptochila grandiflora (Lindenb. & Gott.) Grolle
Cuspidatula monodon (Tayl.) Steph.
Jamesoniella colorata (Lehm.) Spruce ex Schiffn.
J. tasmanica (Hook. f. & Tayl.) Steph.
Jungermannia inundata Hook. f. & Tayl.
J. orbiculata (Col.) Grolle
Lophozia tasmanica Schust.

Gymnomitriaceae

Gymnomitrion incompletum (Gott.) Schust.
Herzogobryum aterrimum (Steph.) Grolle
H. erosum (Carringt. & Pears.) Grolle
H. teres (Carringt. & Pears.) Grolle

TABLE 1 (cont.)

Scapaniaceae

Blepharidophyllum vertebrale (Tayl.) Aongstr.
B. xiphophyllum Grolle
Diplophyllum obtusifolium (Hook.) Dum.

Schistochilaceae

Pachyschistochila parvistipula (Rodw.) Schust. & Engel
P. succulenta Engel & Schust.
P. trispiralis (Schust.) Schust. & Engel
Paraschistochila isotachyphylla Engel & Schust.
P. pinnatifolia (Hook.) Schust.
P. tuloides (Hook. f. & Tayl.) Schust.
Schistochila balfouriana (Hook. f. & Tayl.) Steph.
S. lehmanniana (Lindenb.) Carringt. & Pears.
S. pseudociliata Schust.
S. tasmanica Steph.

Geocalycaceae

Chiloscyphus amplectens (Mitt.) Engel & Schust.
C. archeri Engel & Schust.
C. australis Gott. *et al.*
C. biciliatus (Hook. f. & Tayl.) Gott. *et al.*
C. bispinosus (Hook. f. & Tayl.) Engel & Schust.
C. echinellus (Lindenb. & Gott.) Mitt.
C. excipulatus (Steph.) Engel & Schust.
C. gippslandicus Engel & Schust.
C. lentus (Hook. f. & Tayl.) Engel & Schust.
C. leucophyllus (Hook. f. & Tayl.) Gott. *et al.*
C. muricatus (Lehm.) Engel & Schust.
C. novae-zeelandiae (Lehm. & Lindenb.) Engel & Schust.
C. okaritanus (Steph.) Engel & Schust.
C. pallidus (Mitt.) Engel & Schust.
C. planiusculus (Hook. f. & Tayl.) Engel & Schust.
C. semiteres (Lehm.) Lehm. & Lindenb.
C. subporosus (Mitt.) Engel & Schust.
C. variabilis (Steph.) Engel & Schust.
C. villosus (Mitt. ex Steph.) Engel & Schust.
Clasmatocolea marginata (Mitt. ex Steph.) Grolle
C. notophylla (Hook. f. & Tayl.) Grolle
C. strongylophylla (Hook. f. & Tayl.) Grolle
C. vermicularis (Lehm.) Grolle
C. verrucosa Engel
Geocalyx caledonicus Steph.
Hepatostolonophora paucistipula (Rodw.) Engel
H. rotata (Hook. f. & Tayl.) Engel
Heteroscyphus allodontus (Hook. f. & Tayl.) Engel & Schust.
H. argutus (Nees) Schiffn.
H. billardieri (Schwaegr.) Schiffn.
H. coalitus (Hook.) Schiffn.
H. colensoi (Mitt.) Schiffn.
H. conjugatus (Mitt.) Engel & Schust.
H. cuneistipulus (Steph.) Schiffn.
H. cymbaliferus (Hook. f. & Tayl.) Engel & Schust.
H. decipiens (Gott.) Engel & Schust.
H. fissistipus (Hook. f. & Tayl.) Schiffn.
H. gunnianus (Mitt.) Engel & Schust.
H. heterophyllus (Steph.) Engel & Schust.
H. knightii (Steph.) Grolle
H. levieri (Steph.) Schiffn.
H. limosus (Carringt. & Pears.) Schiffn.
H. lyallii (Mitt.) Schust.
H. multifidus (Steph.) Engel & Schust.
H. physanthus (Hook. f. & Tayl.) Schust.
H. simillimus (Steph.) Engel & Schust.
H. sinuosus (Hook.) Schiffn.
H. supinus (Hook. f. & Tayl.) Schust.
H. tasmanicus (Steph.) Engel & Schust.
H. triacanthus (Hook. f. & Tayl.) Schiffn.
H. weymouthianus (Steph.) Schiffn.
Leptophyllopsis laxus (Mitt.) Schust.
Leptoscyphus expansus (Lehm.) Grolle
Saccogynidium decurvum (Mitt.) Grolle

Brevianthaceae

Brevianthus flavus (Grolle) Engel & Schust.

Plagiochilaceae

Acrochila biserialis (Lehm. & Lindenb.) Grolle
Plagiochila annotina (Menz.) Lindenb.
P. baileyana Steph.
P. circinalis (Lehm.) Lehm. & Lindenb.
P. deltoidea Lindenb.
P. fasciculata Lindenb.
P. fruticella (Tayl.) Hook. f. & Tayl.
P. fuscella (Tayl.) Tayl. & Hook. f.
P. incurvicolla (Tayl.) Hook. f. & Tayl.
P. lyallii Mitt.
P. pleurata (Tayl.) Hook. f. & Tayl.
P. radiculosa Mitt.
P. ramosissima (Hook.) Lindenb.
P. ratkowskiana H. Inoue
P. retrospectans Nees
P. stephensoniana Mitt.
P. strombifolia (Tayl.) Tayl. ex Lehm.
P. wattsii Steph. ex Rodw.
Plagiochilion conjugatus (Hook.) Schust.

Acrobolbaceae

Acrobolbus cinerascens (Lehm. & Lindenb.) Schiffn.
A. concinnus (Mitt.) Grolle

TABLE 1 (cont.)

A. ochrophyllus (Hook. f. & Tayl.) Schust.
Goebelobryum unguiculatum (Hook. f. & Tayl.) Grolle
Lethocolea squamata (Tayl.) Hodgs.
Marsupidium setulosum Mitt.
M. surculosum (Nees) Schiffn.
Tylimanthus pseudosaccatus Grolle
T. tenellus (Hook. f. & Tayl.) Mitt.

Adelanthaceae

Adelanthus bisetulus (Steph.) Grolle
A. falcatus (Hook.) Mitt.
A. occlusus (Hook. f. & Tayl.) Carringt.

Cephaloziellaceae

Allisoniella nigra (Rodw.) Schust.
A. tasmanica Schust.
Cephaloziella arctica Bryhn & Douin
C. exiliflora (Tayl.) Steph.
C. hirta (Steph.) Schust.
C. pulcherrima Schust.

Radulaceae

Radula aneurismalis (Hook. f. & Tayl.) Nees
R. australiana Yamada
R. bucciniferа (Hook. f. & Tayl.) Tayl.
R. compacta Castle
R. multiamentula Hodgs.
R. novaehollandiae Hampe
R. plicata Mitt.
R. ratkowskiana Yamada
R. retroflexa Tayl.
R. tabularis Steph.
R. tasmanica Steph.
R. wattsiana Steph.

Frullaniaceae

Frullania aterrima (Hook. f. & Tayl.) Hook. f. & Tayl.
F. clavata (Hook. f. & Tayl.) Tayl.
F. engelii Hatt.
F. falciloba Tayl. ex Lehm.
F. monocera (Hook. f. & Tayl.) Tayl.
F. pentapleura Tayl.
F. probosciphora Tayl.
F. rostrata (Hook. f. & Tayl.) Hook. f. & Tayl.
F. scandens Mont.

Lejeuneaceae

Acrolejeunea aulacophora (Mont.) Steph.
Austrolejeunea olgae (Schust.) Schust.
Cheilolejeunea albovirens (Hook. f. & Tayl.) Hodgs.
C. campbelliensis (Steph.) Schust.
C. comitans (Hook. f. & Tayl.) Schust.
C. mimosa (Hook. f. & Tayl.) Schust.
Cololejeunea laevigata (Mitt.) Tilden
Colura pulcherrima Jov.-Ast.
C. saccophylla Hodgs. & Herz.
Diplasiolejeunea plicatiloba (Hook. f. & Tayl.) Grolle
Drepanolejeunea aucklandica Steph.
Harpalejeunea latitans (Hook. f. & Tayl.) Grolle
Lejeunea cuspidistipula (Steph.) Steph.
L. drummondii Tayl.
L. norrisii Grolle
L. primordialis (Hook. f. & Tayl.) Tayl.
Nephelolejeunea hamata Grolle
Siphonolejeunea nudipes (Hook. f. & Tayl.) Herz.

genus will be reduced to synonymy. A scholarly examination of this family, with 44 species in this check-list, is clearly the most urgent priority for the liverworts of southern Australia.

The species list for the Schistochilaceae stands on a firm basis, following the detailed recent study of Schuster & Engel (1985). A firm basis for Geocalycaceae, the largest family of liverworts in Tasmania, will be provided when the study of this family to species level, being undertaken by Dr J. Engel and Prof. R.M. Schuster, is completed. At a generic level, Engel & Schuster (1984) cogently argued that *Lophocolea* and *Chiloscyphus* could not be maintained as independent genera, so that species formerly known under *Lophocolea* are now given combinations in *Chiloscyphus*. In addition, their overview argued that many species formerly known under *Chiloscyphus* and all species known under *Tetracymbaliella* should now be transferred to *Heteroscyphus*. The names in table 1 reflect their viewpoint, although one must await their complete revision of all the species before one can be confident of which species do indeed occur in Tasmania. Of the remaining genera in Geocalycaceae in Tasmania, perhaps only *Leptoscyphus* needs clarification, as the name of the Tasmanian species, given here as *L. expansus*, must be viewed as tentative. The species of the genera *Hepatostolonophora* and *Clasmatocolea* are firmly based owing to recent detailed treatments (Engel 1979 and Engel 1980 respectively).

The Plagiochilaceae in Tasmania is firmly based owing to the revision by Inoue & Schuster (1971), as are Acrobolbaceae and Adelanthaceae, except for two questions that have plagued this writer: (i) Exactly how does *Acrobolbus ochrophyllus* differ from *A. cinerascens*, and (ii) Exactly how does *Adelanthus occlusus* differ from *A. falcatus*? In the Cephaloziellaceae, the genus *Cephaloziella* needs revision. So does *Radula* in the Radulaceae; the names presented in table 1 are an amalgamation of various sources, the most recent being Yamada (1984).

The Frullaniaceae is represented in Tasmania only by the genus *Frullania*. Knowledge of its species has been greatly aided by several recent papers of Hattori (1979a, 1979b, 1983) plus a personal communication from Dr S. Hattori in which he (i) casts doubt on the occurrence of *F. deplanata* Mitt. in Tasmania, (ii) points out that *F. engelii* is closely related to, and possibly conspecific with, *F. setchelii* Pears. and *F. pycnantha* (Hook. f. & Tayl.) Tayl., both supposed New Zealand endemics, (iii) asserts that *F. gaudichaudii* (Nees & Mont.) Nees & Mont. is a tropical species, probably not occurring in Australia and certainly not in Tasmania, (iv) believes that *F. scandens* may or may not be conspecific with *F. mooreana* Steph.; if not, the latter is the correct name for the Tasmanian species, and (v) does not recognise the occurrence of *F. spinifera* Tayl. in Tasmania.

The species list of the final family, the Lejeuneaceae, is very reliable due to the overview by Grolle (1982), which gave a firm basis for the list of species of that family.

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The author is grateful for the taxonomic assistance given by Dr J.J. Engel (Chicago), Dr R. Grolle (Jena) and Dr S. Hattori (Nichinan). Without the helpful encouragement of Dr S.J. Jarman (Hobart), this paper would never have been written.

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(accepted 6 April 1987)

MID-MESOZOIC LEAVES FROM NEAR IDA BAY, SOUTHERN TASMANIA, AUSTRALIA

by William D. Tidwell, Jong-Heon Kim and Tatsuaki Kimura

(with three text-figures and three plates)

TIDWELL, W.D., KIM, J.H. & KIMURA, T., 1987 (30:vi): Mid-Mesozoic leaves from near Ida Bay, southern Tasmania, Australia. *Pap. Proc. R. Soc. Tasm.*, 121: 159-170, 3 pl. ISSN 0080-4703. Department of Botany and Range Science, Brigham Young University, Provo, Utah 84602, U.S.A.; Department of Astronomy and Earth Sciences, Tokyo Gakugei University, Koganei, Tokyo, 184 Japan (J.H. Kim is a Korean student studying with Professor Kimura).

Several leaf specimens from a locality in southern Tasmania are described. They are assigned to *Coniopteris websterii* sp.nov., *Cladophlebis indica* (Oldham & Morris) Sahni & Rao, *Pachypteris* sp. cf. *indica* (Oldham & Morris) Bose & Roy, *Otozamites* sp., *Pterophyllum*? sp. and *Conites* sp. The specimen of *Otozamites* sp. is also partially petrified and, thus, gives some indication of its internal tissues. These genera and species suggest a mid-Mesozoic, rather than a Tertiary, age for this locality.

Key Words: Mid-Mesozoic, Tasmania, Coniopteris, Cladophlebis, Pachypteris, Otozamites, Ptilophyllum, Pterophyllum, Conites, Osmundacaulis.

INTRODUCTION

A locality south of Ida Bay in southern Tasmania has yielded numerous specimens of fossil plants (pl. I, fig. 1). This locality lies a few hundred metres to the east and west of the Lune River Road immediately north of its junction with the Leprena Track (text-fig. 1). The plant remains include two osmundaceous species, *Osmundacaulis nerii* Tidwell and Jones (1987) and *O. jonesii* Tidwell (1987), a fossil tree fern *Cibotium tasmanense* Gould (1972), unidentified permineralized conifer wood and the fossilized leaf material of this report. The permineralized plant materials and the leaf impressions were collected together but were not *in situ*. The rock matrix having the leaf impressions also contains petrified fern petioles assignable to *Cibotium tasmanense* Gould and an, as yet, unnamed tree fern. This suggests that the fossil plants from this locality came from the same horizon. Gould (1972) considered the strata from whence these plant fossils were derived as possibly Tertiary.

Although the fossil leaves described in this report are preserved in three dimension, they lack cuticle. In some, however, the outline of the epidermal cells is impressed upon the specimens. These leaf specimens were collected by Neri Webster of Bicheno, Tasmania and Ross Jones of Blackmans Bay, Tasmania. The specimens are deposited in the Tasmanian Museum and Art Gallery.

SYSTEMATIC DESCRIPTION

Filicales

Dicksoniaceae

Genus *Coniopteris* Brongniart, 1849

Coniopteris websterii sp.nov.

Pl. II, figs 1, 2; pl. III; text-figs 2B, 3C(i & ii)

Material

Holotype — Z2296, Paratype — Z2295.

Diagnosis

Leaves mostly fertile; main rachis, 1.5 mm thick bearing pinnae at 6 mm intervals; main rachis and pinna rachis rounded; pinnae, thick, leathery, about 15 mm long, arising alternately from main rachis; first pinnules of pinna arising opposite, later pinnules alternate on the two sides; pinnules of one pinna "commonly" overlapping those of the next and adjacent pinnules of the same pinna; first pinnule consists of short stalk, forking after approximately 0.2 mm into an upward pointing fertile branch and forward and outward pointing sterile branches forked into two to four, lobes projecting over main rachis; upper fertile appendages alternate, consist of long stalk, 1 mm long and terminal sorus; sorus and indusium circular — cordate in lateral compression, about 2 mm wide by 1-1.6 mm high; basal sori generally smaller and hemispherical; sori lying in flat plane or slightly tilted; indusium thick, 200μm wide, marked

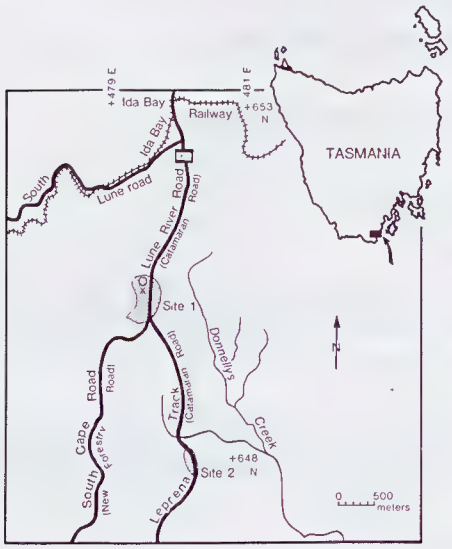

FIG. 1 — Map of southern Tasmania showing collecting sites for fossil plants. Road names in parenthesis are those used on Gould's (1972) index map. O = collection locality for Otozamites *sp. (Modified from Leprena 4818, edition 1, 1985; Tasmania 1:25 000 Landsmap.)*

externally by differential preservation; margins entire; sporangia numerous, not projecting beyond the edge of the indusium, rather small, about 200μm wide, annulus oblique, nearly complete; no spores were observed.

Etymology

The specific epithet honours Neri Webster who collected the specimens of this fern and who has contributed so much to this study.

Remarks

The holotype is fragmental and consists of a single fertile pinna with seven fertile appendages. Sterile leaves are similar to the sterile branches of the first fertile pinnules.

Coniopteris websterii is similar to *C. margaretae* Harris (1961) and *C. simplex* (L. & H.) Harris (1961). It is distinguished in having larger sori than *C. simplex* and having alternate rather than opposite pinnules. The upward pointing fertile branch of the first pinnules in *C. websterii* differs from the forward pointing fertile branch of these pinnules in *C. margaretae*. *Coniopteris websterii* is unlike other species of *Coniopteris*. It, however, resembles *Gonatosorus sphenopteroides* Brick (1937) and *G. nathorsti* Raciborski (1894). Shorter sterile lobes and a much smaller sorus of *G. sphenopteroides* separates it from *C. websterii* and broader, undivided sterile lobes and a smaller sorus separates *G. nathorsti* from *C. websterii*.

Halle (1913) described four species of *Coniopteris* from the Jurassic or Early Cretaceous (Stipanicic & Bonetti 1970) of Graham Land, and Douglas (1973) described fertile leaves or sterile parts of four species of this genus from the Early Cretaceous of Victoria, Australia, but none is similar to *C. websterii*. Based on sterile foliage, *Coniopteris nanopinnata* Douglas has been transferred to *Gleichenites* (Drinnan & Chambers 1986).

Incertae Sedis

Genus *Cladophlebis* Brongniart, 1849

Cladophlebis indica (Oldham & Morris) Sahni & Rao 1933

Pl. I, figs 4, 7; pl. II, figs 5, 6; text-fig. 2A

Material

Z2297, Z2298.

Diagnosis

Five sterile pinna fragments with rather stout pinna axis up to 1 mm wide; pinnules falcate-deltoid in shape, tapering strongly towards apex, typically 11 mm long by 5 mm wide at the base; apices obtusely or subacutely pointed; close, suboppositely or alternately attached by entire base at an angle of 50°; margins entire, slightly recurved; laminae contiguous near base; midrib is distinct, extending to tip; lateral veins katadromic, 8-9 pairs, forking once; basiscopic basal vein occasionally forked twice.

Comparisons

The leaves of only a few reported *Cladophlebis* species resemble *Cladophlebis indica* in having entire, falcate pinnules and singly-forked lateral veins (Retallack 1980). Among these species similar to *C. indica* are *C. nebbensis* (Brgn.) Nathorst (1878), *C. acuta* Fontaine (1889), *C. grahamii* Frenguelli (1947), and *C. oblonga* Halle (1913). The latter two species were reported from Jurassic or Early Cretaceous strata of Graham Land. *Cladophlebis nebbensis*, although poorly preserved, has pinnules that appear less falcate, less tapered and more obtusely pointed, whereas, the pinnule apices in *C. acuta* are more acute than in *C. indica*. *Cladophlebis grahamii* differs from *C. indica* by the former species having its basal lateral vein occasionally forking twice and the basal acroscopic margins of its pinnules being subauriculate.

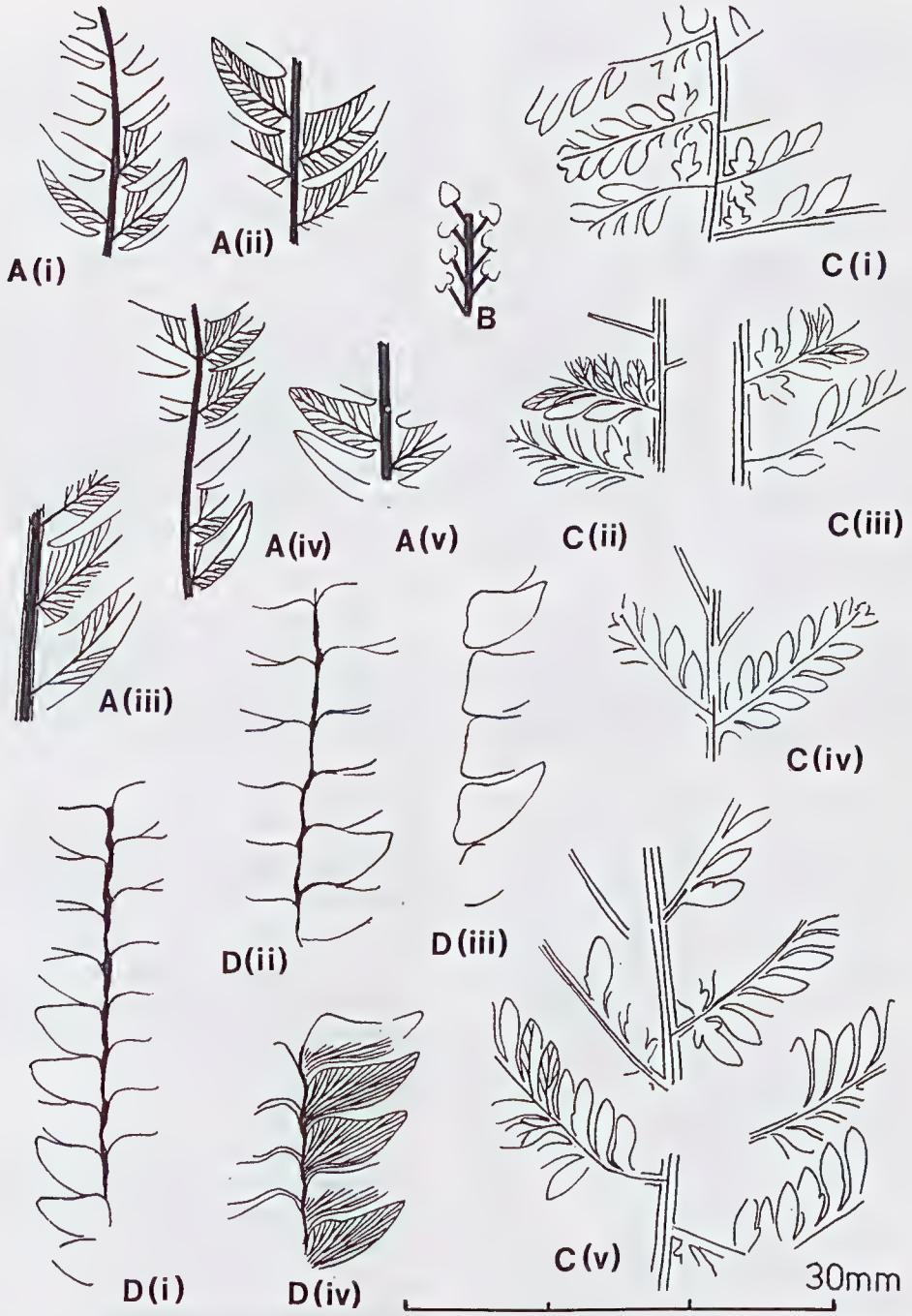

FIG. 2A(i-v) — Cladophlebis indica *(Oldham & Morris) Sahni & Rao showing various forms of pinnules (i); from Z2298. (ii-v) from Z2297; x 2; 2B* — Coniopteris websterii *sp. nov. from Z2296; x 2; C(i-v)* — Pachypteris *sp. cf.* indica *(Oldham & Morris) Bose & Roy showing venation (i,vi,v), from Z2301; (ii,iii) from Z2300; x 2; 2D(i-iv)* — Otozamites *sp., showing pinna-form and venation from Z2302; x 2.*

Cladophlebis oblonga is closest to *C. indica* and is distinguished from this latter species by its less-tapering pinnule apices (Retallack 1980). Based upon some fertile specimens, Bose & Sah (1967) transferred *C. indica* to *Todites indicus*. Retallack (1980), however, considered them separate taxa and, noted that when fertile fronds of *C. indica* are collected, they will probably be osmundaceous.

The present pinna fragments are similar to those of *Cladophlebis australis* (Morris) Seward (1904) and *C. biformis* Drinnan and Chambers. *Cladophlebis australis* is known extensively from Triassic strata in the Southern Hemisphere (see Herbst 1978, Retallack 1980, 1983). In fact, the species name *australis* was given originally by Morris (1845) to Tasmanian Triassic leaves. *Cladophlebis australis*, in a strict sense, has relatively erect, falcate pinnules with entire or slightly undulating margins (Retallack 1983). *Cladophlebis biformis* was reported from the Lower Cretaceous Koonwarra Fossil Bed on the South Gippsland Highway south of Leongatha, Victoria (Drinnan & Chambers 1986). In *C. biformis*, the entire margined, falcate pinnules have acute apices and are distichously arranged. Both of these species have lateral doubly-forking veins throughout their pinnules which contrasts with the single-forking veins of *C. indica*. *Cladophlebis australis*, as loosely identified in the past, has been incorrectly regarded as the most widespread, long-ranging and common fern of the Gondwanan Mesozoic (Retallack 1983). However, as pointed out by Retallack (1983), if Morris' original illustrations are followed then *C. australis* would be restricted to Middle and Late Triassic rocks of eastern Australia and Argentina.

Cladophlebis indica is a long-ranging taxon that has been found in both New Zealand and India (Retallack 1980).

Some species of *Cladophlebis* have been regarded as members of the Osmundaceae (Townrow 1963, Harris 1961, Andrews 1970). *Cladophlebis indica* may also belong to this family. Petrified fern stems assignable to *Osmundacaulis* fossilized with this foliage (Tidwell 1987, Tidwell & Jones 1987), suggest such assignment may be correct (Medwell 1954, Douglas 1969).

Pteridospermales

Genus *Pachypteris* Brongniart, 1828

Pachypteris sp. cf. *indica* (Oldham & Morris) Bose & Roy 1967

Pl. II, fig. 4; text-figs 2C(i-v)

Material

Z2299, Z2300, Z2301.

Diagnosis

Leaf at least bipinnate with a rather thick rachis, 1 mm wide with a median groove, ultimate pinnae arise alternately at an angle of about 50°; pinnae elongate-oblong in outline, 15 mm long and up to 8 mm wide, 5-8 pairs of pinnules arising katadromically together with a terminal one. Pinnules generally short-oblanceolate or ovate in outline; apices obtusely pointed or blunt, pinnules attached to pinna axis at a narrow angle, decurrent, forming a narrow web, 0.5 mm wide along both sides of pinna axis; typically 5 mm long and up to 1.5 mm wide; veins *Sphenopteris*-type; three pairs of simple or once forked lateral veins arise from midrib; basal pinnules give rise to a pair of deeply dissected lobes; these pinnules attached at a wide angle or perpendicular; veins invisible; a single shallow lobe present only on the acroscopic side in some pinnules (text-fig. 2C(ii)); no pinnule at very base of pinna or on rachis between adjacent pinnae; cuticle not preserved.

Remarks

Specimens consist of five fragments of isolated leaves. Although detailed cuticular features of these leaves are unknown, they appear to be similar to the seed fern *Pachypteris*. Epidermal cells of the upper epidermis were observed in the pinnule impressions of these specimens (text-fig. 3B). These cells appear to have had straight walls and are almost isodiometric in shape. However, they are slightly elongated over the veins. No stomata were observed. Because of their incompleteness, it is difficult to make a definite identification to species of these leaves. However, they are sufficiently similar to *Pachypteris indica* to tentatively assign them as *Pachypteris* sp. cf. *indica*. *Pachypteris indica* has been reported from the Middle to Upper Jurassic Kachchh localities (Bose & Banerji 1984) and the Lower Cretaceous Jabalpur Series (Bose & Roy 196 ') of India.

Comparisons

Pachypteris specifica Feistmantel known from the Lower Cretaceous of India (Bose & Banerji 1984) and *P. lanceolata* Brongniart reported from the Middle Jurassic of Yorkshire (Harris 1964) are similar to the Tasmanian *Pachypteris* specimens. However, they are distinguished from each other by their size, the presence of pinnules on the main rachis and their respective venation.

Pachypteris sp. cf. *indica* is also similar to *P. crassa* Townrow, and *P. austropapillosa* Douglas. *Pachypteris crassa* was collected from Upper Triassic sediments at the Langloh coal mine,

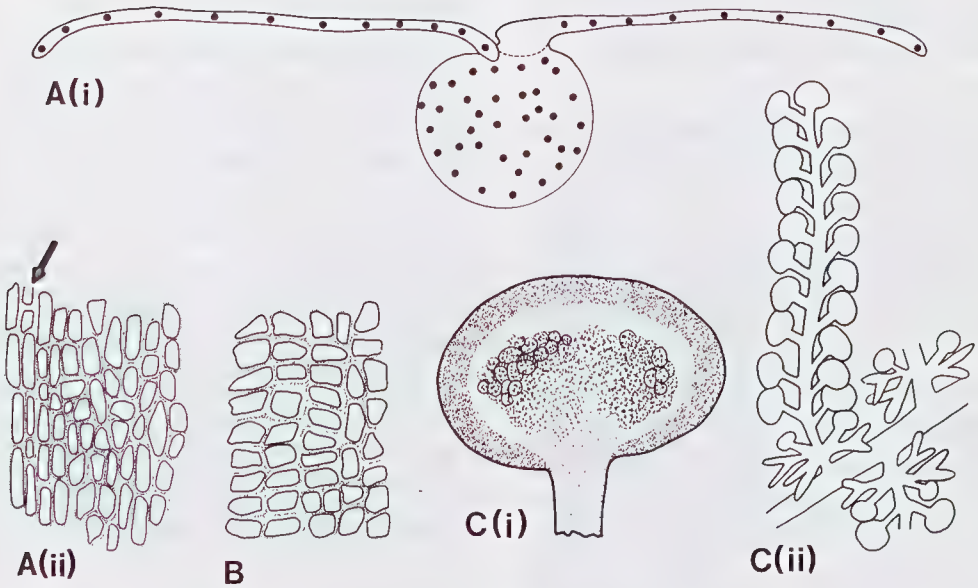

FIG. 3A(i-ii) — Otozamites *sp. (i) cross-section of petiole and lamina. Black dots represent vascular bundles and veins, Z2302; x 20. (ii) epidermal cells of the upper lamina and a vein (arrow); x 10; 3B* — Pachypteris *sp. cf.* indica *(Oldham & Morris) Bose & Roy. Epidermal cells of the upper lamina, Z2301; x 100; 3C(i-ii)* — Coniopteris websterii *sp. nov. (i) enlargement of sorus containing sporangia; x 10. (ii) showing distribution of sori, Z2296; x 2.5.*

Hamilton, Tasmania (Townrow 1965). *Pachypteris crassa* differs from *Pachypteris* sp. cf. *indica* by being larger, having slightly contracted pinnule bases and having pinnules that are joined together by a wing of tissue along the pinna rachis. This wing gives a bilateral symmetry to the rachis of *P. crassa* that does not appear in *P.* sp. cf. *indica*.

Pachypteris austropapillosa, described from the Lower Cretaceous of Victoria (Douglas 1969), differs from P. sp. cf. *indica* by being larger, having undulate pinnule margins, rounded apices and more perpendicular aspects in its pinnule attachment.

Sterile and fertile pinnules in *Coniopteris frutiformis* Douglas (1973) are attached to each other. The sterile pinnules of this species are similar to *P.* sp. cf. *indica* and its fertile pinnules are like *C. websterii*. However, the sterile pinnules of *C. frutiformis* lack a midrib which is present in *P.* sp. cf. *indica* and the sterile pinnules of *C. websterii* are dissected, unlike those of *C. frutiformis*. The fertile pinnules of *C. websterii* are continuous to the apex of the pinna (pl. III) whereas upper portions of the fertile pinna of *C. frutiformis* are sterile.

Bennettitales

Genus *Otozamites* Braun, 1842

Otozamites sp.

Pl. II, figs 2, 3; text-figs 2D(i-iv), 3A(i-ii)

Material

Z2302

Diagnosis

Leaves nearly parallel-sided for the most part, elongated, up to 15 mm wide; apex and base unknown; pinnae falcate-deltoid with rather expanded acroscopic basal angle; acroscopic margin concave, basiscopic margin mostly convex, contracted and slightly decurrent near base; typically 7.5 mm long, 2.5 mm wide at middle; pinna apex obtusely or subacutely pointed; pinnae close, overlapping, suboppositely attached to upper edge of slender, round rachis (up to 2.5 mm wide) by lower portion of inner edge of pinna base at a right angle; upper half of base free; expanded acroscopic basal angle often overlapping succeeding basiscopic pinna base; veins originated from the attachment of pinna, five in number at base, upper three fork

twice and radiate to the acroscopic angle and margin; lower two fork twice, each ending at the distal basiscopic margin; cuticle not preserved.

Remarks

This specimen of *Otozamites* sp. is characterized by its small size and elongated leaf composed of falcate-deltoid pinnae with strongly marked and free acroscopic angle.

The fossil is preserved in an unusual manner. It is intermediate between a cast and a petrification. The specimen has the external impressions of the *Otozamites* leaves, but the bulk of the foliage is still embedded in is matrix which was sectioned.

In cross-section, *Otozamites* sp. consists of round rachides with attached "gull-wing" shaped pinnae (text-fig. 3A(i)). Although poorly preserved, various components of the rachides can be observed. The epidermal and hypodermal tissues of the rachides cannot be separated and the ground tissue inside these structures appears to be parenchymatous. However, the outline of these cells is not often seen and most of it is disorganized into a brown humus-like substance. Complete layers of thick-walled mechanical tissue similar to sclerenchyma surround the vascular bundles. Up to forty vascular bundles occur in two rather vague circular bands. The inner circle is situated within an outer circle which is near the epidermal-hypodermal region. The other bundles are randomly distributed. No resin cavities appear in the rachides or in the mesophyll of the pinna.

Bundle configuration is not known in other species of *Otozamites*, but it is known in some species of the Bennettitales such as *Ptilophyllum amarjolense* Bose, *P. sahnii* Gupta and Sharma and *Dictyozamites* sp. (Bose & Kazat 1970a, 1970b). In these, the bundles are arranged in double U's which are unlike the more or less scattered bundle configuration in the rachides of *Otozamites* sp.

Vascular bundles can be observed in the lamina as black dots but their anatomy is difficult to determine. The upper and lower cuticles appear to be thin and about the same thickness. It is difficult to distinguish the cuticle from the epidermis. No attached trichomes were noted. Stomata were not recognized on the upper surface of the lamina, which seems to be covered by an unbroken epidermis. In some areas, stomata can be seen in the lower epidermis, lying in the lamina between bundles. Although not perfectly preserved, the guard cells seem to be at an oblique angle usual in gymnosperms (Stopes 1910). Surfaces of the guard cells are thinly cutinized. The apertures do not appear to be arched. No hypodermal layer was detected.

The mesophyll, although not well preserved, appears to have been well developed and consisted of one, possibly two, layers of closely packed cylindrical cells 12μm wide and 50μm long. Their walls appear thin. Throughout the remainder of the leaf, the mesophyll cells are round to irregularly shaped.

Outlines of polygonal epidermal cells are preserved in impressions of the leaves (text-fig. 3A(ii)). The cells over the rachis are rectangular to occasionally rectangular spindle-shaped (30-40μm long by 15μm wide) and round hair bases appear to be present. Stomates were not observed.

Impression of the upper epidermis shows the epidermal cells between the veins are rectangular to polygonal and are parallel to subparallel to the veins (pl. I, fig. 6). The cells over the veins are elongated in longitudinal rows and are of a more uniform rectangular shape. Cell walls are moderately marked, rather broad and straight. No evidence of trichome bases is present. Lower epidermis was not observed.

Comparisons

Specimens from the Boola Boola forest (Lower Cretaceous) that were first described as *Otozamites* by Douglas (1962, 1963) and later transferred to *Ptilophyllum* (Douglas 1969), resemble this Tasmanian specimen in pinna size, but they are distinguished from each other by the strongly developed acroscopic angle of the pinna in the *Otozamites* specimen from Tasmania.

This Tasmanian *Otozamites* species resembles most closely in leaf form and size the species *O. bengalensis* (Oldham & Morris 1863) Seward (1917) which is, according to Bose & Kasat (1970a), synonymous with *Ptilophyllum cutchense* Morris. *Otozamites* sp. can be distinguished from the above mentioned Indian species by its very different pinna form and by having venation which radiates from the base of the pinnae rather than more or less parallel veins arising from the entire pinna base as in *Ptilophyllum*.

The small leaves of *Ptilophyllum bengalense* (Oldham) Schimper from the Liassic plant-bed of North Iran (Kilpper 1968) and *Otozamites walkamotaensis* Bose & Zeba-Bano (1978) from Kachchh, India resemble in pinna form those of *Otozamites* sp. *Ptilophyllum bengalense* and *O. walkamotaensis* are distinguished from *O.* sp. by their pinnae not being distinctly auriculated, by the venation in *P. bengalense* being coarser, simple or once forked and the higher number of veins (8-14)

in *O. walkamotaensis* which fork one to three times.

Ptilophyllum spinosum described by Douglas (1969) from the Lower Cretaceous of Victoria, Australia is similar in leaf form, size and pinna form to *Otozamites* sp., but is distinguished from this latter taxon by its densely crowded veins (ten in number at the base) that fork only once. The Tasmanian leaves were placed in *Otozamites* instead of *Ptilophyllum* because of the presence of strongly marked and free acroscopic basal angle in the pinna of the Tasmanian specimens. Based upon this feature, it is likely that *Ptilophyllum spinosum* Douglas is closer to the genus *Otozamites* than to *Ptilophyllum*. It is difficult to distinguish *Otozamites* from *Ptilophyllum* by their cuticular characters alone.

There is also a possibility that these Tasmanian leaves might belong to *Ctenozamites*, but the slight radial divergence of the leaves of *O.* sp. makes it unlikely that they belong to the former genus.

Genus *Pterophyllum* Brongniart, 1828
Pterophyllum? sp.
Pl. I, figs. 3, 5

Material

Z2303

Remarks

The only specimen in this flora that can be assigned to this genus is a single pinna fragment that unfortunately is only represented by its basal part. The pinna is 9 mm wide at its base and is attached to the side of a slender tachis. It is slightly expanded at its base. The parallel veins arise from the rachis at an angle and are simple and nine in number. The basiscopic veins are bent slightly downwards at their point of origin. Cuticle was not preserved. Because of its incompleteness, this fragment is only provisionally assigned to *Pterophyllum*.

Gymnosperm — Incertae Sedis

Genus *Conites* Sternberg, 1823
Conites sp.
Pl. I, fig. 2

Remarks

Very small cone scales resembling *Conites* occur in the matrix of the specimen containing *Otozamites* sp. (Z2302). None of these scales are attached to a cone axis. Based upon size and shape, they most closely approximate the scales of *Conites* sp. B from India (Bose & Banerji 1984).

DISCUSSION

The leaf specimens constituting this report, various osmundaceous species and two genera of tree ferns were collected on the slope and flat areas (Pl. I, fig. 1) east and west of the Lune River Road, north of the junction with the Leprena Track. A basalt, containing siliceous amygdules and xenoliths of silicified sediment, crops out on the ridge above and west of the locality and extends southwards. Gould (1972) thought the fossil material may have been derived from weathering of the pale, leached sediments interbedded with or just beneath the basalt, or from the xenoliths in the basalt itself. However, the thick vegetational cover obscures the actual original site(s) of the fossil plant remains. As pointed out by Gould (1972), there is not any direct evidence for the age of these sediments. However, based upon a suggested Tertiary age for the basalt, he thought them to be Tertiary. Upper Triassic coal measures containing silicified wood occur north of this fossil locality. Gould (1972) considered the preservation of this Triassic wood to be different from that of the petrified fern he described from the Lune River Road–Leprena Track site (fig. 1). The fossils from this latter locality appear to be too young to be Triassic and are certainly older than Tertiary.

Based upon the occurrence of the pteridosperm *Pachypteris* and bennettitalean *Otozamites*, there is little doubt that the geological age of the collecting site for *Cibotium tasmanense* Gould, *Osmundacaulis nerii*, *O. jonesii* and the fossil leaf materials comprising this report is Mesozoic. It is difficult to make a precise age determination of the plant bed within the Mesozoic because of the insufficiency of the fossil material.

In comparing this Tasmanian flora with the flora from the Middle Jurassic Walloon Coal Measures of Queensland, none of the fossil plant species reported by Gould (1974, 1981) from this strata are the same as those from the Tasmanian locality. Anatomically, *Osmundacaulis hoskingii* Gould (1973), is the closest, but it differs in various ways from the Tasmanian species (Tidwell 1987, Tidwell & Jones 1987). The other species of petrified osmundaceous stems from the Walloon Coal Measures are also different from the Tasmanian axes. These latter species have been transferred to *Millerocaulis* (Tidwell 1986).

It is most likely that the strata of this Tasmanian plant bed is Late Jurassic-Early Cretaceous

in age. As presently known, *Pachypteris* species or pteridospermous plants with small pinnae and pinnules as in the Tasmanian specimens are predominant in the Upper Jurassic and Lower Cretaceous plant beds in India (Bose & Banerji 1984), Argentina (Archangelsky 1963a, 1963b, 1964) and South Africa (Anderson & Anderson 1985; their gen. A. sp. A and gen. B. sp. A), and smaller *Otozamites* (or *Ptilophyllum*) species such as these from Tasmania are predominant in the Lower Cretaceous plant beds in Australia (Douglas 1969). Because *Cladophlebis indica* has been recorded from the Upper Triassic to Lower Cretaceous plant beds (Retallack 1980), the sterile fern leaves of this species are useless for precise age determination.

The *Osmundacaulis* species (*O. nerii* and *O. jonesii*) from this locality are like *O. hoskingii*, but are most similar to *O. natalensis* (Schelpe 1955) Miller and *O. atherstonei* (Schelpe 1956) Miller from the Lower Cretaceous of South Africa. Erasmus (1978) identified two new species of *Osmundacaulis* from the Lower Cretaceous of South Africa. The anatomy of these two species is exceptionally close to *O. nerii*, *O. jonesii* and other, as yet undescribed, osmundaceous species from this Tasmanian locality. The inner and outer sclerotic rings which are found surrounding the petiolar vascular strands in *O. nerii* also occur in one of Erasmus' species. These two species, as well as another *Osmundacaulis* species (*O. lemonii* Tidwell) from the Late Jurassic of Utah, are the only taxa with these unique tissues.

Based upon the fossil evidence, this flora appears to be either Late Jurassic or Early Cretaceous and, most likely, Early Cretaceous in age. Because of the lack of angiospermous fossils, this flora is probably from older Lower Cretaceous strata.

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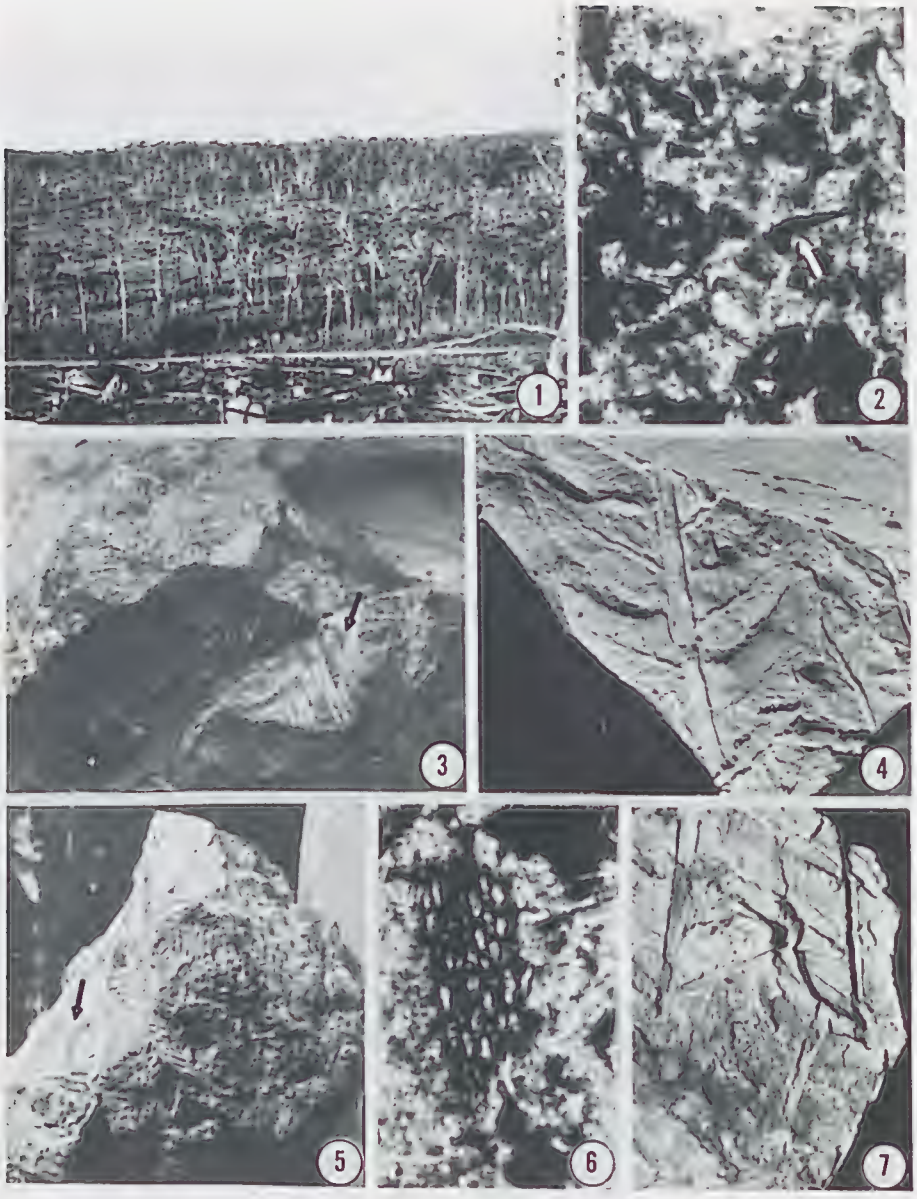

PLATE I

1. *View of collecting locality. Collecting sites are in the flattened area in the foreground and on the slopes in the background (photo by Ross Jones).*
2. *View of separate cone scales (arrow) of* Conites *sp. in the matrix of specimen Z2302: x 10.*
3. *Portion of* Pterophyllum? *sp. showing pinna fragment (arrow), Z2302; x 1.8.*
4. *Pinnules of* Cladophlebis indica *(Oldham & Morris) Sahni & Rao, Z2298; x 2.5.*
5. Pterophyllum? *sp. pinna base (arrow), Z23030; x 1.*
6. *Cuticle of* Otozamites *sp., Z2302; x 10.*
7. *Pinnules of secondary pinnae of* Cladophlebis indica *(Oldham & Morris) Sahni & Rao, Z2297; x 2.*

PLATE II

1-2 Coniopteris websterii *sp. nov. 1, a fertile pinna fragment, Z2296; x 2. 2, enlargement of 1; x 4.*

3. Otozamites *sp. A bundle of leaves consisting of more than 30 leaves preserved in parallel in the area of 50 mm x 30 mm, Z2302; x 2.*

4. Pachypteris *sp. cf.* indica *(Oldham & Morris) Bose & Roy, a bipinnate leaf fragment, Z2300.*

5-6 Cladophlebis indica *(Oldham & Morris) Sahni & Rao. 5, a pinna fragment, Z2298; x 2. 6, a bipinnate leaf fragment, Z2297; x 2.*

PLATE III

1. Coniopteris websterii *sp. nov. (Specimen in the collection of Neri Webster); x 4.*

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